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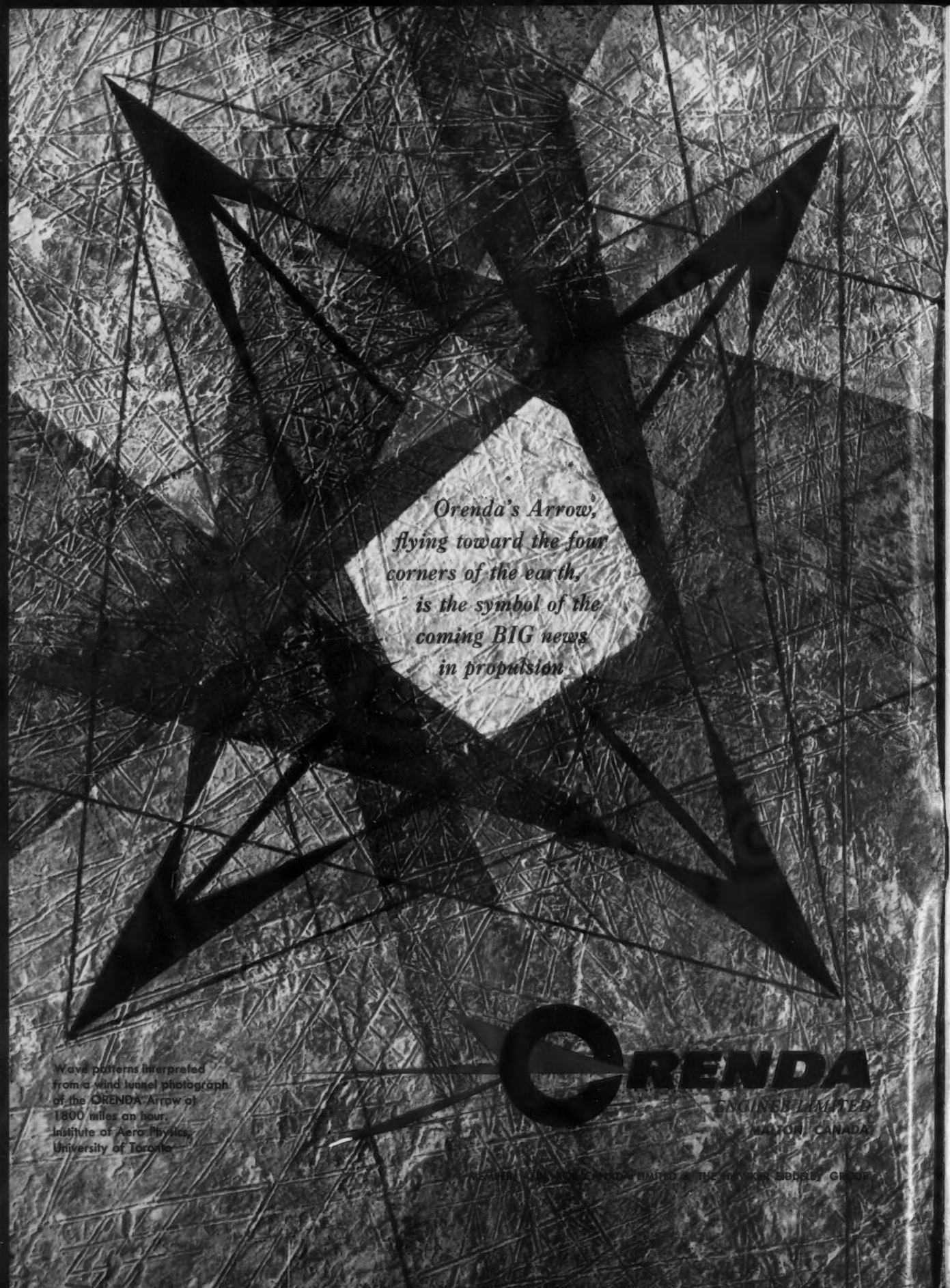
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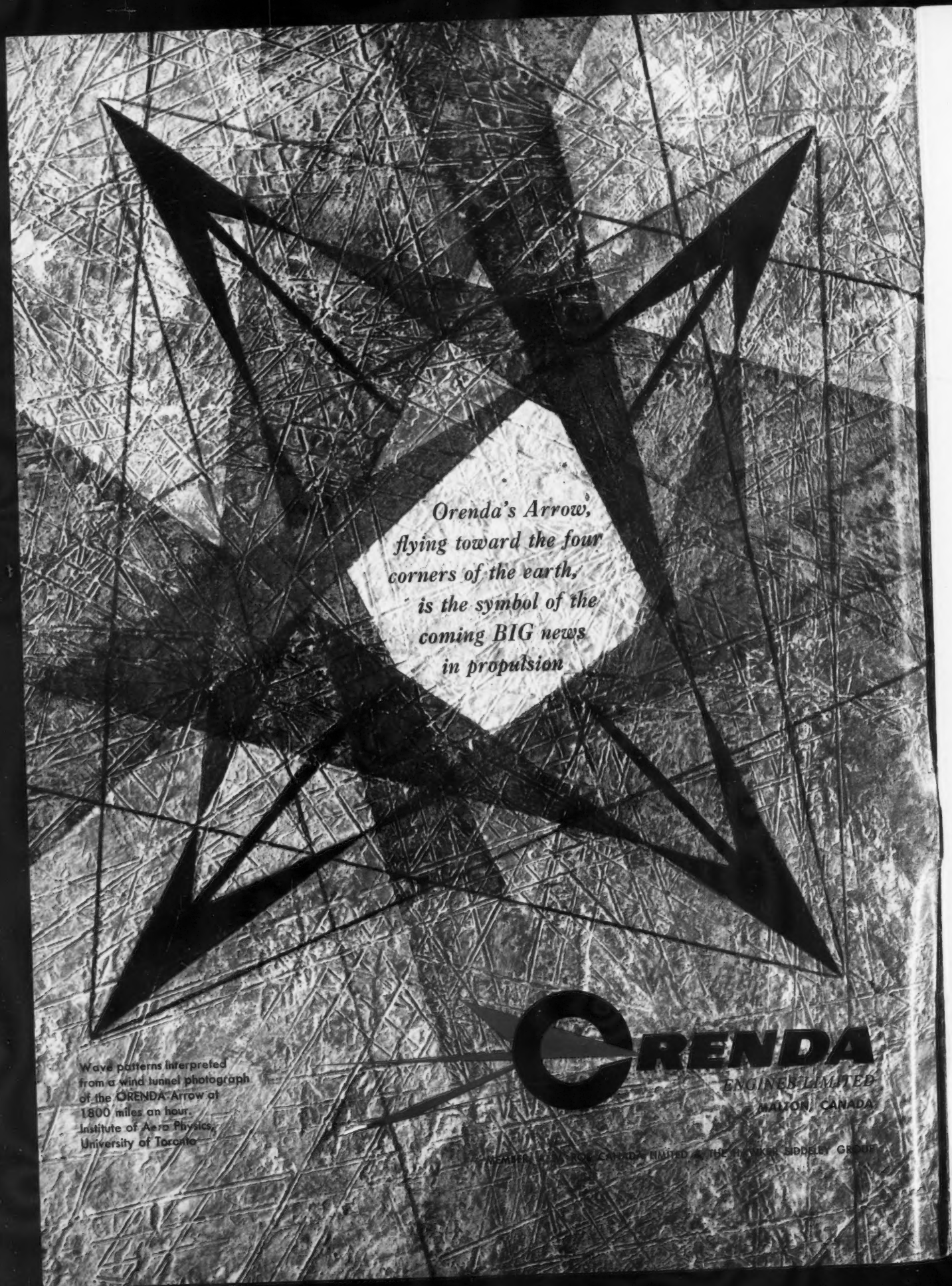
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WHERE WE STAND WITH HELICOPTERS

IT IS ONLY over the past ten years that helicopters have shown the rate of progress which has been associated with fixed wing aircraft for decades. The advancement of conventional aircraft received two tremendous boosts during the two world wars, but the helicopter was not a working proposition in the 1914-18 war, and it became reasonably practical for specialized uses only in the concluding stages of the 1939-45 war.

The mathematics of the helicopter proved to be complex and new types of physical experience were continually encountered. It was therefore a vehicle that repaid particular care in the early stage and a cautious yet imaginative approach; above all it demanded considerable capital investment in laboratory and test facilities. This had to be provided in the teeth of other competing demands for technical manpower and factory equipment needed for new aircraft, engines and missiles.

But because of the progress of modern technology the rate of advance of helicopters has been sustained and to-day they are in ever widening operational use throughout the world. Nevertheless, the 6,000 or so helicopters built to date in all countries represent little more than six months' combined output of fixed-wing aircraft in Britain and the United States. So helicopters still form only a small fraction of airframe weight produced.

Whilst pioneering beginnings have been made in the fare-paying passenger use of helicopters, the maturing of helicopter commerce will still take some time. However, the expanding military use of helicopters is amassing a variety of operational experience in latitudes from the tropics to the Arctic Circle that will help materially towards the development of more economic commercial helicopters.

Helicopters were used in quantity for the first time in Korea when they took part in tactical operations for their intrinsic capabilities and not merely as a useful adjunct to other forms of transport. The reliance that came to be placed on them is evident in one memorable operation when 12 helicopters moved an equipped battalion onto a Korean hilltop in six hours. British forces have made increasing use of the helicopter in Malaya and other areas when communications are difficult.

In the civil field, it is foreseen that expanding use will be found for helicopters as flying cranes; airlifting special equipment to remote spots; as means of inspecting cables and pipe lines; for geophysical surveys and many other purposes, which, coupled with accumulated military experience, will lead to economic scheduled freight and passenger services.

The Bristol Sycamore was the first helicopter of British design to be used operationally. A single-engined general purpose aircraft it is in regular military service in many parts of the world, in climatic and altitude extremes, as well as with the Services and British European Airways at home. The first Sycamore to visit the North American continent has now been extensively operated across Canada. The Bristol Type 173 twin-engine tandem rotor helicopter, which has been developed from the Sycamore, is the forerunner of larger machines which are expected to see service first with the Services.

Looking into the future the need is for helicopters able to lift bigger loads—of 10,000 lb and more. Successful development of these heavy helicopters will in time see the replacement of the piston engine by gas turbines; Bristol is well advanced with plans for a turbine-powered version of the twin-engined helicopter as part of its progressive programme towards meeting the mounting requirements of civil and military helicopter operators.

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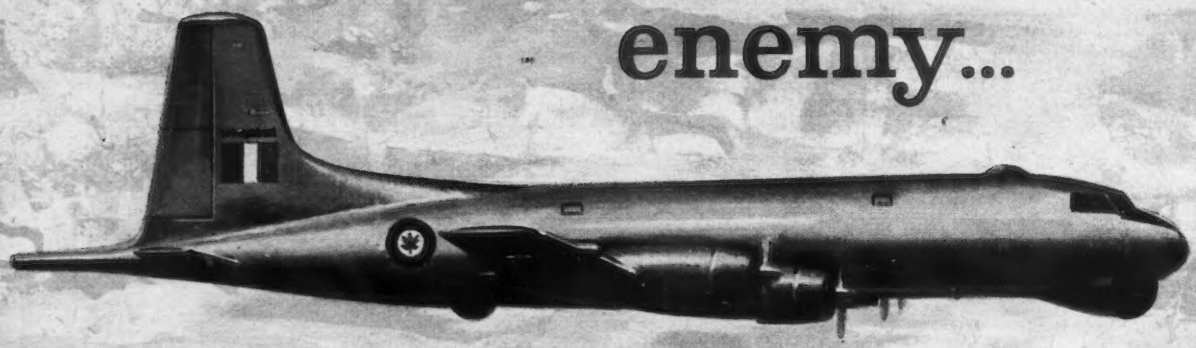

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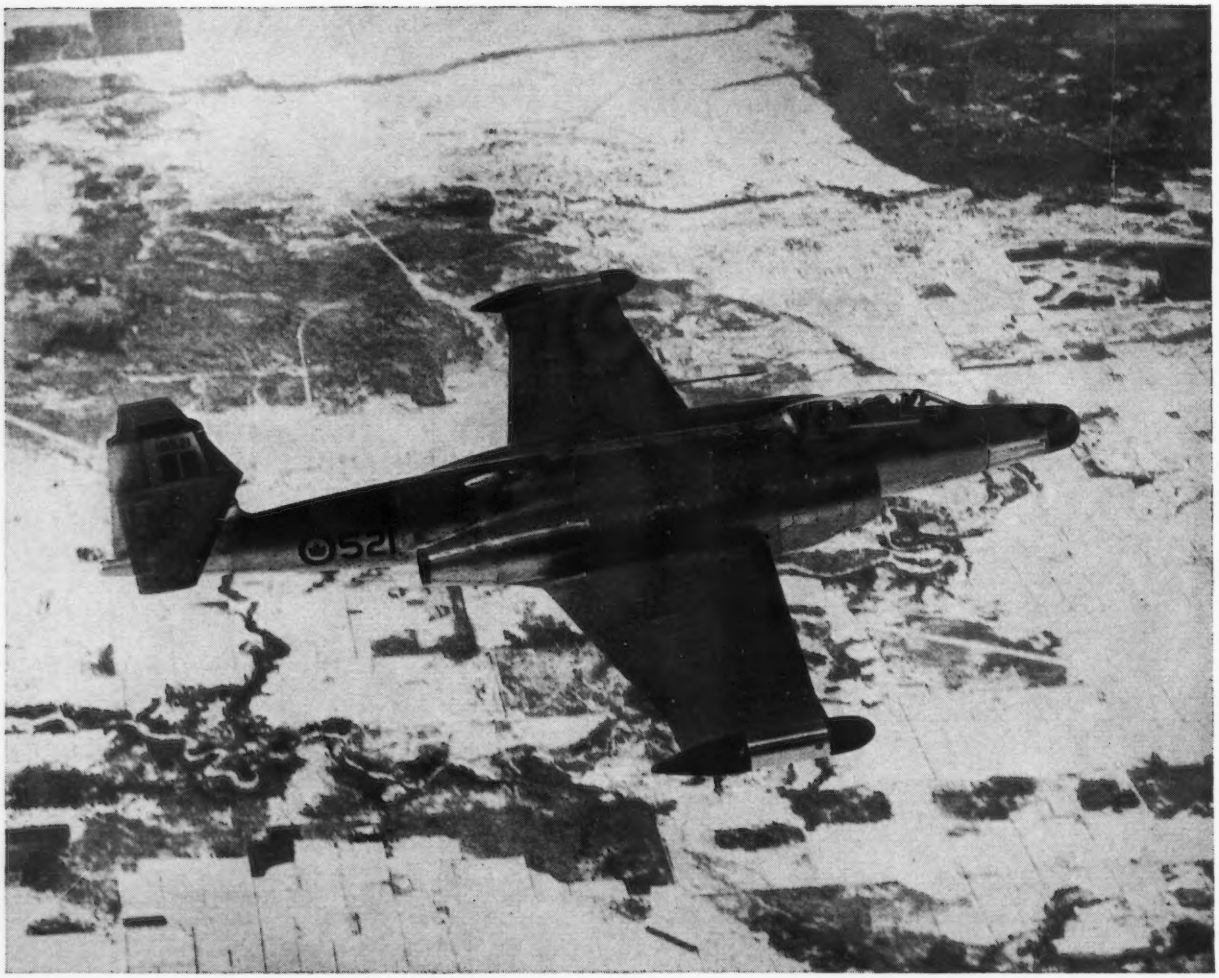
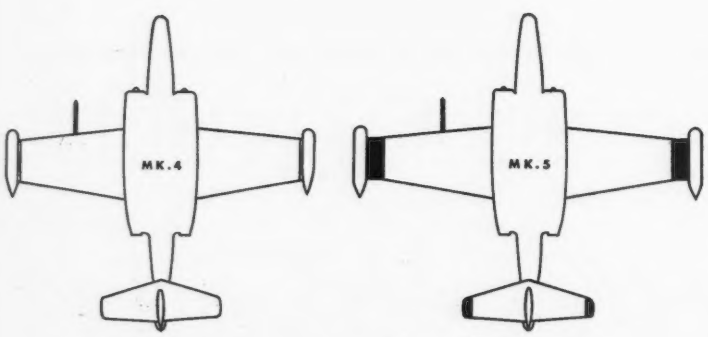
CF-100 MK. 5





CF-100 Mk. 5 (Orenda 11) recently introduced by Avro Aircraft Ltd. The principal difference from the Mk. 4 lies in the extension to the wings and tail surfaces, as shown in the accompanying silhouettes, and certain weight reducing measures which together have given an improved altitude performance.

EDITORIAL

AIR FLOW vs SHEAR FLOW

THE design of a modern aircraft involves not only the application of a wide range of sciences and skills, but demands from each the best performance possible within the current state of the art. To achieve this requires the services of many different kinds of specialists, but the direction and co-ordination of all these various specialized activities is primarily the responsibility of the aeronautical engineer. His task is to provide the basic design concept and to weld all of the different components into an integrated system, be it a weapon or a means of transport.

It is a standing joke that each specialist considers his own particular field of activity to be the most vital phase of the aircraft design, and this is perhaps most apparent in the case of aerodynamics which has assumed an unwarranted degree of glamour and prestige. Without attempting to resolve the question of relative importance, it does seem that this particular misconception regarding the supposed pre-occupation of the aeronautical engineer with aerodynamics is leading to some undesirable consequences.

A recent analysis of major design functions in the Canadian aircraft industry reveals the following distribution of professional staff:

Design	
Preliminary Design	3%
Structural Design	15%
Mechanical Design	10%
Engine & Equipment Installation	20%
	48%
Analysis	
Aerodynamics & Performance	15%
Stress and Weight Analysis	20%
	35%
Test	
Structural Test	5%
Component and Systems Test	7%
Flight Test	5%
	17%

From the foregoing it can be seen that while aerodynamics accounts for something less than 25% of the staff, the various structural aspects totalling almost 50% constitute by far the greatest proportion of the design effort. Nevertheless, recent graduates display a singular lack of interest in the latter subject, to the extent of expressing a 10:1 preference for employment in the very much smaller field of aerodynamics.

These figures indicate a serious need for re-orientation of our educational effort to produce a better balance between the various interests which an aeronautical engineer must have. As one of our leading aircraft designers has commented

> "We badly need a smattering of Southwell, Pippard, Hoff, Shanley, Pugsley, Cox, et al on the Canadian scene. Most of the boys have never even heard of these people – let alone read any of their papers!"

Similarly, our research and development programmes are sadly deficient in this same respect. Thus, while much effort is being directed toward improvements in aerodynamics or propulsion, it is perhaps not generally realized that the success of any aircraft is equally dependent upon efficient structural design. Much more emphasis should be given to increasing activity in this field by the Universities, Government Laboratories and Industry.

J. L. ORR,
Chairman, Ottawa Branch.

AMENDMENT OF THE BY-LAWS

ANNOUNCEMENT BY THE COUNCIL

THE President appointed Mr. H. C. Luttman, F.C.A.I., Mr. W. Symmons, M.C.A.I. and F/L W. J. Szostak, Technical Member, to act, under the terms of Regulation No. 13, Section 3, as scrutineers of the voting on the proposed Amendment of the By-laws, referred to on page 38 of the February issue of the Journal (Vol. 2, No. 2). The following is the scrutineers' report:

"The voting on the four groups of Amendments was counted at the Headquarters of the Institute in the morning of the 24th March 1956; the results were

	Votes cast	In favour	Not in favour
For Group i	540	527	13
For Group ii	542	525	17
For Group iii	541	512	29
For Group iv	540	537	3

Three of the ballot papers were spoiled.

H. C. Luttman
W. Symmons
W. J. Szostak, F/L"

In accordance with Section 2 of Article 13 of the By-laws, a resolution amending the By-laws must be decided on a two-thirds majority of the votes cast. Since this majority has been attained in the case of each group, the four groups of Amendments are deemed to be adopted. Accordingly the Amendments will now be submitted to the Secretary of State for approval.

H. C. Luttman
Secretary
Dated the 6th April 1956 For the Council

COMMENT

It will be remembered that the above-mentioned groups of Amendments comprise the following:

Group i

An amendment to Article 5 to arrange the election of Councillors so that each Branch will be represented on the Council as follows,

A Branch having up to 400 members	2 Councillors
A Branch having 401-599 members	3 Councillors
A Branch having 600 members or more	4 Councillors

Group ii

An amendment to Article 6 to enable the Council to elect more than one Vice-President, at its discretion.

Group iii

An amendment to Article 10, Section 2, firstly to increase the annual dues to include the subscription to the Journal and secondly to enable the Council to reduce the rate of dues payable by overseas members, and

Group iv

Amendments to Articles 8, 9 and 10 to clarify the wording of these Articles, without introducing any substantial changes.

EFFECTIVE DATE

These Amendments, though now adopted by the voting members of the Institute, do not become effective until they have been approved by the Secretary of State.

In the meantime the original By-laws stand; the election of the members of the Council for 1956-57 must follow the old formula; only one Vice-President may be elected by the new Council; and the annual dues for 1956-57, payable by overseas members admitted before the proposed Amendment becomes effective, must remain as they are at present. (The other part of the Group iii Amendment introduces certain administrative advantages but it has no effect on the amounts which individual members have to pay.)

The chief benefits to be derived from these Amendments cannot therefore be applied, in the main, before the year 1957-58.

ECONOMY TOOLING†

by R. J. Higman*

Canadair Limited

SUMMARY

Today's keen competition in the aircraft industry outlaws the war-time approach to manufacturing with its policy of "get the plane built, whatever the cost"! Today's aircraft markets require that the utmost economy be exercised to hold down costs wherever possible.

Recognizing that one of the sources of high cost is tooling, the article deals with a tooling philosophy which can best be termed as similar to that held on tooling and costs as it was before the war years.

The "Economy Tooling" philosophy has been applied at Canadair and there are many examples given, with photographs and statistical data, of its direct application to present day tooling needs.

THE WAR YEARS' TOOLING PHILOSOPHY

MANY years have passed since the aircraft manufacturer has been faced with the problems connected with low quantity, low rate production. War-time aircraft manufacturing required an output far in excess of the industry's capacities and, all during this period, the emphasis was on maximum production with minimum effort. In addition to the shortage of capacity, there was the parallel problem of limited availability of skilled labour. These two factors alone dictated a policy to the manufacturer which resulted in the establishment of tools and facilities of the very best quality and, because production programs were at a high rate, many times for open-end quantities, the funds available were more or less unlimited and such a policy was justified.

The tools not only had to be of a very substantial design, capable of producing many hundreds or thousands of parts or assemblies within close tolerances, but they also had to be of a design which a relatively unskilled worker could understand easily and use with a minimum of instructions. The tools had to be fabricated so that it was nearly impossible for the worker to make a mistake in producing the parts. War-time production rates were so high that the most economical production could best be achieved by breaking each manufacturing operation down into as many stages as possible, thus permitting a maximum number of people to work on the product at any one time. Even then, at times, it was necessary to provide duplicate tooling in order to meet the desired production rate; this added the requirement of dimensional control through the use of masters, to the complexity of the tooling programs.

After the cessation of hostilities, the continued demands of military and civil aircraft users, along with the need for preparedness in the event of another military crisis, justified the continuation of these tooling policies established during the war years, though in some cases the need for duplicate tooling was considerably reduced. For some manufacturing programs, we began to think of ourselves as "mass producers", even considered our production problems to be similar to the automotive and appliance industries, and began to think in terms of automation and single purpose tooling philosophies.

At the same time design technological improvements were taking place, resulting in a more and more complex aircraft. These improvements were, in part, possible because of the larger production quantities and higher production rates, making it possible to justify larger expenditures for improved methods which, in turn, produced a better product. Other improvements were required by the designer to enable him to meet the performance specifications. Whatever the reason for advancements, they are now a necessary part of our production techniques and will remain with us in order that we may compete in so far as product performance is concerned. To be sure, it can only be expected and, in fact, we look forward to further advancements which will result in a better product.

TODAY'S MARKET REQUIREMENTS

Many of the aircraft manufacturing programs today do not have the high-rate, large quantity requirements associated with manufacturing during the last 15 years. In fact, these programs are very similar to the typical programs of pre-war years, when a total quantity of 50 aircraft, at a rate of 1 or 2 per month, was considered a very large order. A common contract in the late '30's covered 13 large military aircraft, with deliveries spread over 18 to 29 months; for fighter aircraft, the quantity on a large order might go as high as 75 with little hope of getting any continuing production. The problem then resolves itself into the question of what we can consider

†Paper read at the C.A.I. Annual General Meeting in Toronto on the 20th May, 1955.

*Manager, Manufacturing Engineering Division.

a reasonable level of tooling cost in the light of the new or, if you like, the old type of production now being contemplated. It is obvious that we will likely put ourselves out of business if we spend funds for tooling to the extent to which most of us are accustomed.

On the other hand, we still have to cope with the technical improvements designed into the aircraft. We must comply with accepted standards of part and component interchangeability; we must handle new materials, such as 75S aluminum alloys, magnesium, titanium and the like; we must be capable of manufacturing by new processes, such as metal-bonding, honeycomb construction, glass-cloth and phenolic resin assemblies and high strength weldments. We certainly cannot do the job the way it would have been done for a typical war-time aircraft production program and live with our conscience regarding cost. We must become old-fashioned and by old-fashioned I mean have a good look at the way the job was done before we had the expansion of war-time production. We must use the skilled labour now available in a more direct approach so that it is applied to the end product to a greater extent than in the recent past.

The rapid growth, resulting in such substantial expansion of our tooling requirements, occurred over the last 15 to 20 years with no real break in the upward trend. A review of the experience in the industry shows that there is less than 1 person in 20 that has had more than 15 years experience and less than 1 in 30 that has had 20 years experience. This indicates that at the best there is only 1 person in 25 presently engaged in our manufacturing organizations that is intimately familiar with production methods used before the war. In other words, in our factories, on an average, there are 20 to 25 persons who were trained during this expansion period for every one that can boast of the "good-old-days". It is not likely, therefore, that we can depend upon the experience in our factories to be of any sizeable help in solving our problem.

A TOOLING PHILOSOPHY FOR TODAY'S MARKET

We, therefore, must establish a tooling philosophy, which would control the extent of tooling expenditures commensurate with size of the program. Simply stated, *a tool should be provided only when the cost of that tool plus the production cost of the operations performed with the tool are definitely less than would result if no tool were used.* This means that careful consideration must be given to the value of every tool. If a tool is mandatory, the analysis is easy, but in many cases we have been accustomed to calling for tools which are not justifiable under lower rate production.

At this point in planning, a second or third look at the requirement often will reveal that the skill required to produce the tool can be applied more effectively to the manufacture of the part and, in fact, would produce a better part. I am not suggesting that we use toolmakers to build our product, but I do suggest that we give the production worker the opportunity to use his skill to the fullest extent and that a condition be promoted which will induce a sense of accomplishment in the worker so that he feels responsible for the article he produces. After a tool has been found necessary, every effort has to be exerted to ensure that it is of a minimum cost and will produce the quality and quantity of parts required.

The fabrication of detail parts tools, capable of adjustment for a variety of parts, needs to be employed to the fullest extent. The use of lower cost materials for tool fabrication is mandatory if economy is to be realized – such as cyanide hardened 1010 steel bushings, or no bushings at all, in place of precision tool steel bushings, plastic tool materials in place of metal and the use of wood and other non-metallic materials in place of steel or light alloys. Optical methods for major jig erection and large machine tool alignment could help materially to eliminate the cost of masters and maintain the tolerances required in large components. The cost of jig fabrication can be substantially reduced by the elimination of machining on heavy jig frames by such devices as the use of loose frame locators and supporting the members of the jig structures in Hydro-stone. Building multi-purpose assembly fixtures and reducing the number of assembly stages must be employed to the utmost for real economy. Adjustable machine fixtures, such as the Whorton Universal Jig System in place of conventional single part machine fixtures, offer a promising saving if used with discretion.

For large programs the use of production methods and personnel for fabricating the simpler types of small tools, such as hydro-press blocks and templates, can be a real money-saver and will promote a healthy condition for extending the economic philosophy to the production phase of the work.

Other real savings are available from the judicious use of improved shop methods – such as the adaptation of standard machines in lieu of specialized equipment, the use of impact rubber forming for the tough forming part, the use of the high pressure Gruen forming process, such as that employed by the Verson-Wheelon machines, and the use of modern machining techniques involving carbide tip cutters and proper application of cutting fluids.

CO-ORDINATION BETWEEN ENGINEERING DESIGN AND TOOLING

A large reduction of tooling costs in the aircraft industry would result from the simplification of engineering design. This is not an easy problem to solve and requires a very thorough appreciation of the shop problems by the designers. In most cases, by the time an engineering release has reached the planning stage, where the shop problems have their first chance to be highlighted, there is insufficient time for redesign and it is not unusual for the planner to overlook possible design improvement. The engineer should always look at his design and ask questions – such as, can I reduce the number of parts in this assembly; are these joggles, holes, cut-outs, notches, etc. necessary; are the tolerances called for on this design the maximum that can be allowed and can they be easily understood from the information given; and last, but not least, is the material called for the most suitable from the standpoint of ease of fabrication that will accomplish the purpose required by the design?

Complications are often added to the manufacturing process because portions of a part are unnecessarily refined in order to look good or because the designer

has done too good a job. There are too many cases where the increased manufacturing costs result from small improvements in stress distribution and the costs are far out of line for the benefits gained.

The engineer can materially assist the manufacturing department in minimizing tooling and production costs by standardizing the design of the aircraft as much as possible. Typical construction throughout the aircraft should be used wherever possible and detail parts and assemblies should be as similar as possible. It is not uncommon to find minor assemblies throughout the structure which appear the same, except for possibly the overall length, and yet when the detailed design is released, it is apparent that each one is a separate part requiring a complete set of tools because of variations in minor dimensions. With a little effort, these designs could have been made, with no sacrifice in strength or weight, so that the parts could have been fabricated in a universal tool requiring only minor adjustments for one dimension.

TOOL DESIGN SIMPLIFICATION

These same design principles apply to the tool designs, whether they be for major assembly jigs or small bench or machine tools. There is no excuse for elaboration for the sake of appearance or convenience. In considering any tool, the simplest possible configuration should be used. A thorough down-to-earth analysis of all improvements must be made which evaluates the basic necessity — is the improvement a real benefit or is it something just nice to have?

THE TOOL INSPECTION ATTITUDE

Inspection personnel also have an influence on our tooling expenditures. At times their over-critical eye can increase the cost of a tool and establish an air of mystery around the tooling problems, causing the toolmakers to use unnecessarily accurate techniques and elaborate methods to maintain tolerances closer than those necessary to accomplish the job at hand. The inspector should confine his control to the production of satisfactory parts and should not let his desire to have perfect parts (a commendable attitude) result in undue extra costs to the tool fabricator or production department.

CONCLUSION

In preparing for any manufacturing program, we have only one goal in mind — that of producing a quality article at minimum cost. On small quantity production runs, a large share of this cost will be represented by tools and we have a real job of re-aligning our thinking to take advantage of the simplified methods used by the aircraft producer of the 30's. We will still produce a product of ever improved design criteria and continue to improve our techniques, but the only road for this type of production is old fashioned and down-to-earth, without the glamour associated with wart-time conditions.

APPENDIX

SUPPORTING STATISTICAL DATA

Tables 1a and 1b — Comparison between the economical tooling approach and the more usually adopted practices.

Project A is that which has been dealt with by the re-adjusted approach. It can be seen that in comparison with Project B the rate of tools per part has been reduced by as much as 0.4. Tooling per pound of airframe has been reduced by as much as 1.5. Considerable savings are seen in the man-hours per tool factor. In comparison with Project C as many as 68.6 hours per tool have been saved. In Project C 10,907 tools were produced and projecting into this the tooling philosophy of Project A, assuming that 68.6 hours could be saved on each tool, would be a realization of some 748,220 man-hours. It is worthy of note that Project A is for a much larger aircraft than those in Projects B and C. This can be seen by reference to Table 1b. It is also a fact that Project A only calls for 50 aircraft, whereas B and C run into several hundred. These factors are mentioned to support the earlier statements regarding the necessity to economize.

TABLE 1a
TOOLING

Projects	Tools	Parts	Tools per Part	Tools per lb. of Airframe	Initial Tool Man Hour Estimate	Shop Budgeted Tooling Hours	Man Hours per Tool	Parts per lb. of Airframe
A	80.000	80.000	1.0	1.41	2.740.000	2.190.300	27.4	1.41
B	22.106	15.720	1.4	2.90	1.270.000	1.263.120	60.0	2.16
C	10.907	8.372	1.3	1.85	1.935.480	1.047.072	96.0	1.42

TABLE 1b
PRODUCTION

Projects	Unit Man Hours	Airframe Weight	Man Hours per Lb.
A	600.000	56.700	10.6
B	152.000	7.278	20.85
C	68.250	5.896	11. 6

SOME QUESTIONS AND ANSWERS

Many questions will present themselves to the reader and some of these can be foreseen.

1. "*How many man-hours are involved in the maintenance of cheap tools?*"

   First, let us define and analyze the words "Cheap Tools". Our definition of cheap is the elimination of costly and superfluous machining, the reduction of heavy steel location devices, the use of lighter metal bases and the elimination of "Spit and Polish". With these thoughts in mind, our tool maintenance problems are no greater than they were heretofore. In fact, where larger assembly jigs are concerned, our problems and time consumption have been lessened. This has been brought about by the use of optical methods. Since the system eliminates the large com-

posite type masters, periodical checks and reworks can be performed in a few hours, whereas before, a similar operation would take days or even weeks. The technique of our philosophy requires less parts to the tool, a minimum of bushings and a minimum of moving components. These conditions must result in less wear and, therefore, less maintenance. Another factor worthy of note is that where cheap tooling has been produced, seriously damaged tools can be completely replaced at a combined cost that would still be less than one tool under the original policy.

2. "*How will you apply the skills available as related to the future potential of high production?*"
Accepting that such a potential does exist, we shall be in a position we have been in many times before; that of using unskilled labour with little or no aircraft experience. We have stated earlier that the type of tooling produced must be adequate for the job it has to perform. We have also agreed that the skill of the user has to be applied to a greater extent. This then resolves itself into one of two possibilities; on the one hand, improvements in the tooling and on the other, education of the user. If we take the first possibility, I am sure you are ready to accept that, having once produced a tool at minimum costs, refinements could be added to improve its function at a very conservative figure; the total sum being a lot less than the conventional tool. Further, where conditions demand it and with the advantage of experience gained, a new tool could be produced in all probability at a combined cost that is still relatively low. Considering the second possibility, our past experience has shown that, by good training techniques, unskilled labour can be educated to produce good products in a very short space of time.

3. "*Is there a danger of destroying the creative "Art" of the tool designer and toolmaker?*"
If we mean, is there a danger of destroying the thing of beauty, which they sometimes produce for beauty's sake, the answer is yes. If we mean, do we endanger the creative ability of these people, the answer is no. Having had years of experience in their respective fields, it has been found that they have a definite tendency to follow an established pattern. This pattern is the result of their training and their associations. If a man has been accustomed to producing tooling for the manufacture of watches or optical instruments, his mental attitude toward tooling is highly precise. He cannot be compared with the person who has aircraft tooling experience. Familiarity with the product and with the types of tooling produces an air of confidence in the man. Generally speaking, he can design or produce a tool without over-exerting his mental capacity. When an entirely different approach is proposed to him, his first reaction will be resentment – such comments as "What are these people trying to do, make me a hammer and chisel man?" are often overheard. As the program progresses and as the philosophy is emphasized, his resentment will be replaced by a feeling of being challenged – "So they do not think I can make cheap tools". At this stage, we regain the man's enthusiasm and a new more searching creative force goes into action. The result is that instead of destroying the Art, we are stimulating it and directing it into new and less conventional channels. The knowledge that the man originally possessed cannot be destroyed; he is now adding to that knowledge and using his past experience to achieve a different Art. It has also been evident that the men who possess the wider experience are those who have the least difficulty in producing tooling under this new philosophy. Their experience equips them to determine what can be done and what cannot be done.

In considering these questions and others, we must also realize that tool designing or tool making can be a complex operation. However, one should not lose sight of the fact that tooling in all its aspects can be resolved into a series of small mechanical problems. A systematic analysis of the overall requirement, dealing with one section and one problem at a time, is the only approach that can result in an economically successful conclusion. In the aircraft business, assembly jigs, when completed, can appear as a gigantic conglomeration of locators and formers. A closer study reveals the similarity between one position and another and the relative simplicity of design.

ECONOMY TOOLING PHILOSOPHY APPLIED

Examples of the conventional and economical tooling approaches are illustrated in the accompanying pictures.

Example 1

Figure 1 depicts a typical aircraft sub-assembly. The proportions are approximately 2½′ long by 8″ wide. The detail parts will be produced with all the holes in the web and no holes in the longitudinal extruded angles. The transverse stiffeners and clip angles are produced with all holes pre-drilled. In all cases, the holes are No. 40 pilot size. The assembly of the parts would be determined by the web, which is located by two ¼″ diameter tooling holes. The longitudinal extruded angles would be checked for end relation to the web and the separation would also have to be controlled. The location of the transverse angles and clips would be achieved by co-ordination, using the No. 40 pilot holes and Cleeco clips. After removal from the jig, complete drilling transfers would be made and the parts riveted together.

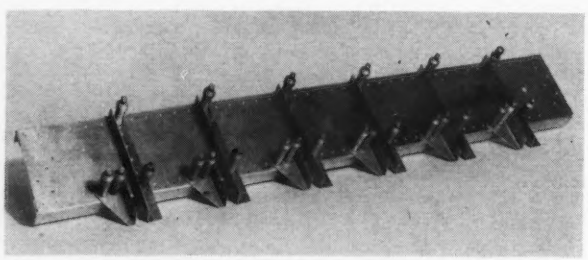


Figure 1
Web Assembly

Figure 2 illustrates the conventional type tool to achieve this operation. Locations are provided for all the conditions and the respective details. The tool as designed and produced will definitely perform the operations required. It will certainly produce its quota of 50 assemblies. It is rigidly constructed and well made; in fact, it is a darn good jig. "*Too good!*" This tool con-

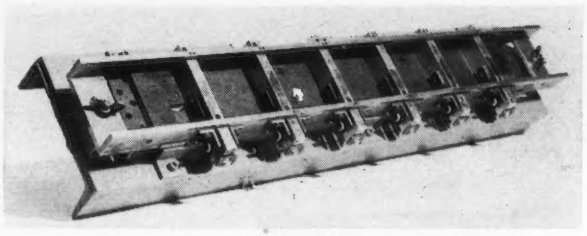


Figure 2
Conventional Jig for Web Assembly

sumed 45 to 46 hours of tool design and 106 hours of fabrication time. These times are not excessive for the job that has been produced but, comparing this with the economy philosophy, it is far too much.

Figure 3 shows a tool for producing the same assembly by exactly the same methods. As you can see, it is not elaborate nor is it pretty. Nevertheless, it is a tool and it will produce 50 parts at the very least. The construction is rigid without being heavy, it is accurate without being expensive and the detail part areas are completely accessible. The construction comprises a 1/16″ thick photo reproduced template, in which has been located the two web tooling holes. Reinforcing the template and serving as locators for the extruded longitudinal angles, are three pieces of steel angle suitably positioned. The end-of-part check for the extrusions is afforded by a short steel angle, suitably positioned. On the top side, serving as locators for the transverse angles and clips, are six pieces of masonite board. These are machined to width for a local area on one side, which controls the separation and position of the details. The

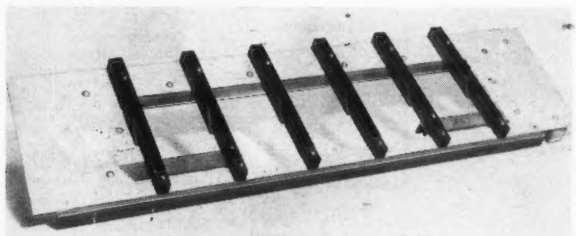


Figure 3
Economy Jig for Web Assembly

attaching of the jig components is done by screws and rivets. The fact that the main body of the jig is a photo reproduction of the actual assembly considerably reduces the time factors required to achieve location of the components. This tool required no detailed tool design, a free-hand sketch is all that is necessary, time 1 hour, so the total make-time including design was 6½ hours. This compared with the conventional tool of 151.6 hours certainly justifies the change in approach.

Example 2

In Figure 4, we see an illustration of an aluminum aircraft fitting. It is machined on two faces to produce an angle of 93° 51′. Side faces are machined to produce the 1.80″ dimension. (Section B-B). Three holes have to be drilled pilot size into the part, final sizing of the holes being achieved on the next assembly.

Figure 5 shows the result of the tool designer's and toolmaker's endeavours to produce a drill jig for the part. As before, we are only required to produce 50

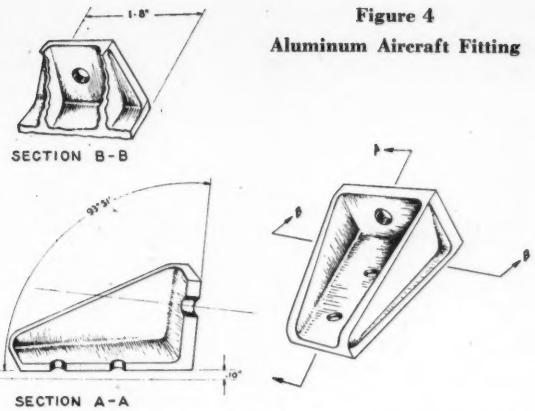


Figure 4
Aluminum Aircraft Fitting

details. Important also is the fact that the holes to be drilled are pilot size. The jig will do the job, but again it bears no resemblance to the economical tooling approach. This type of tooling for 50 parts cannot be accepted today as the correct method of tooling.

Figure 6 shows a jig which will produce three holes at the correct disposition in the same part. Location of the part is achieved by two faces in contact with the 93° 51′ angle surfaces and two pins to register the part from the 1.80″ dimensions; "C" clamps are used to retain the part in the jig. Right and left hand parts can be produced in this tool, whereas two tools of the other type would be required. You may feel that accuracy

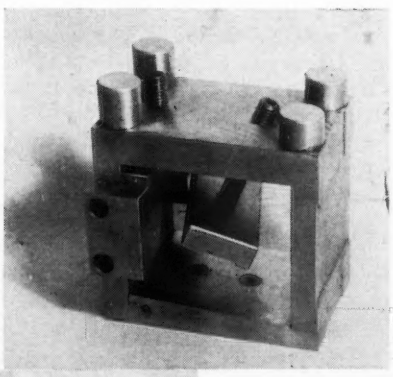


Figure 5
Conventional Jig for Aircraft Fitting

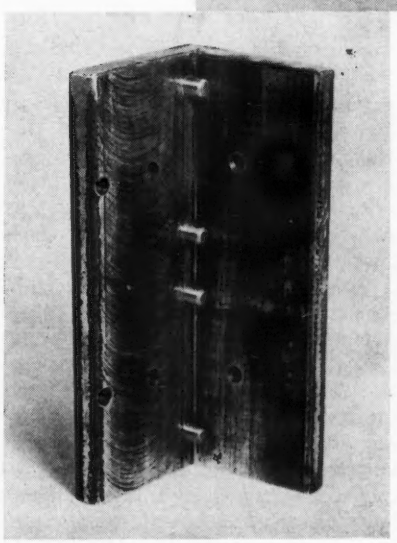


Figure 6
Economy Jig for Aircraft Fitting

is not a feature of the tool in Figure 6. Do we need accuracy for pilot holes? Each part must be dealt with on its merits and the conditions of the parts or assemblies satisfied. There is little purpose in building into any tool accuracies and refinements that are never needed.

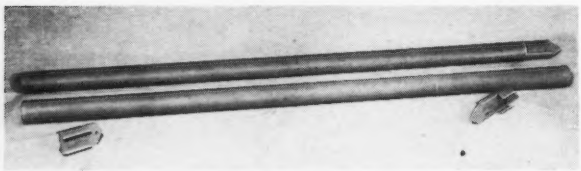


Figure 7
Strut Details

Example 3

Earlier in this presentation, we referred to the aspects of common tooling for a variety of parts, we also touched on the aspects of the engineer's approach to this problem. We are all familiar with the type of strut shown, unassembled, in Figure 7, and detailed in Figure 8, which appears in many variations of size and length of tube, type of end fittings, and angular arrangement and centre-to-centre pitch of rivets attaching the end fittings to the tube. Do you not think that some of these variables could be made common? Do you think that variations of 1° in angular arrangement or .050″ on pitch of rivets, which occur commonly in practice, can be justified by their designers? These are the questions we should ask ourselves when designs such as there are originated. You may well imagine the difficulties that the planner and tool designer are faced with when they are asked to produce a common tool for conditions such as these. Their time in arriving at the desired result, is in some cases, out of all proportion to final tool making time. Nevertheless, it is necessary in light of the circumstances. Tools were produced for these assemblies and two attempts had to be made before economical tooling was achieved.

Figure 9 is a photograph of the first attempt. Here a jig was produced into which the tube was engaged to drill the location holes for the rivets. You can see that this is not a common tool and the variants of the parts would necessitate a tool for each. The end fittings are not catered for in this jig and thus a series of assembly drill jigs would have to be provided to accommodate the various struts.

Figure 10 depicts the results of a concentrated effort to produce a semi-common tool. It can be seen that the jig has a fixed and an adjustable plate. This provides for the variation in length of the struts. In these plates are a series of identified holes which accommodate the variation of the end fittings. The small tubular parts shown in the jig photograph are for the purpose of accommodating the variation in diameter, rivet pitch and rivet angle. The projecting lugs provide the means of register and attachment. With this type of tool, the end fittings and tube are assembled together in the jig and all the parts are drilled in one operation. Cleeco clips are employed to maintain the relativities, while the assembly is removed and riveted together. Five such jigs had to be produced to cater for the condition demanded by the designers. Approximately twelve strut assemblies are produced in each tool.

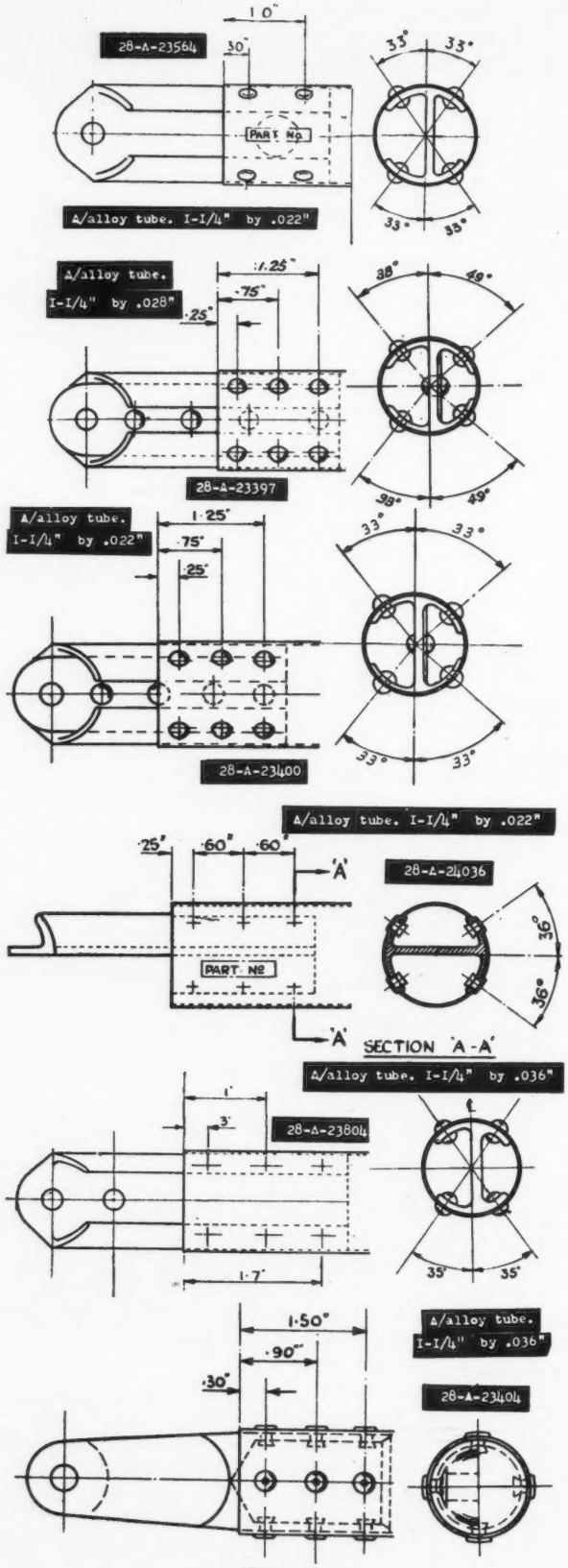


Figure 8
Details of Struts

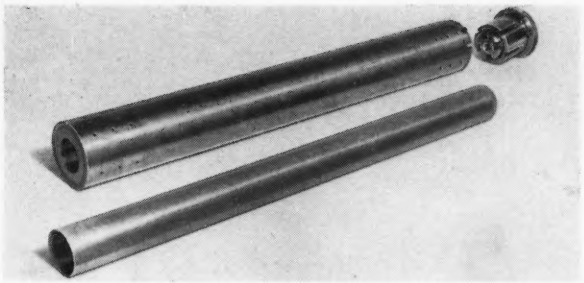


Figure 9
Conventional Jig for Strut Tubes

Example 4 — Major Jigs

We have dealt with some of the aspects of economy tooling where small sub-assemblies and detail parts are concerned. Now let us take a look at some of the larger types of tools. Since the introduction of optical methods in our company, many changes in techniques have been seen. Our original conception of jig building and designing have radically changed. One of the most advantageous features which has developed is a practice which we call "correction at the point of attachment". To appreciate this, one must be specific and deal with a definite tool. Let us take, as an example, a skin panel assembly jig, proportions approximately 24′ long by 6′ high, carrying locations for 12 rib sectors and 6 stringers for one hand and 13 rib sectors with 6 stringers for the other hand. The structure is designed so that one frame serves left and right hand, one on each side. From this one tool are produced 7 right hand and 7 left hand skin panels. This necessitates a set of former boards for the various attitudes of stringers and other details within the assembly. Careful planning and tool designing resulted in producing 83 formers to service all the conditions. Had the tools been produced as separate units, one for each panel, 175 formers would have been required. If we estimate that each former costs $50.00 to produce, the difference for formers alone is $4,600.00. This does not take into account the six extra structures that would also have been required.

Figure 11 is a picture of a similar jig. Projecting from the upper main tube of the frame can be seen a series of short tubes; similarly, tubes project in the opposite attitude from the lower frame. These tubes will constitute the means of "correction at the point of attachment". Hydro-stone is used to fill these tubes after the location device has been positioned. Optical reference lines are located on the jig and a simple spreader bar, with two targets attached, is used to position the locators.

Figure 12 shows the condition clearly. The bar can be seen in position with the upper and lower locator set. Optical line target is seen just behind the bar. These are viewed by the telescopes and enable a constant condition to be achieved. The bar is similarly located at each former station. In this manner two datum holes and two station register faces are consistently located. This method also enables bench work to proceed on the formers at the same time as the structure is being built. The spreader bar is used to transfer the two datum holes and two target points into the formers. The target points are introduced purely to enable periodical checking to be carried out.

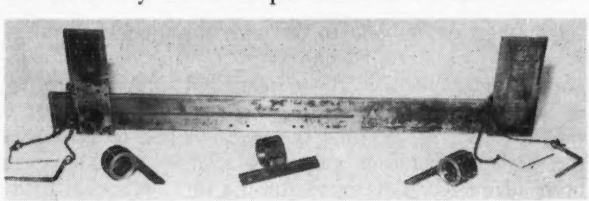


Figure 10
Economy Jig for Strut Assemblies

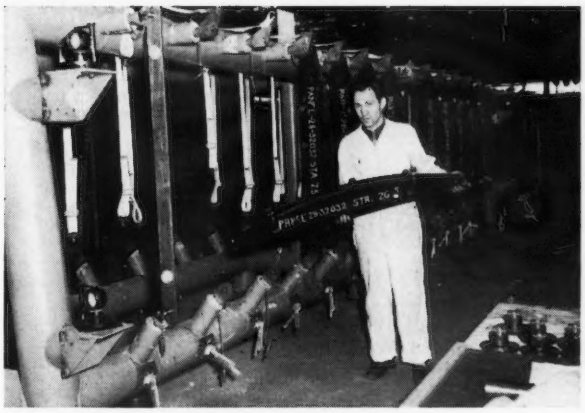


Figure 11
Skin Panel Assembly Jig

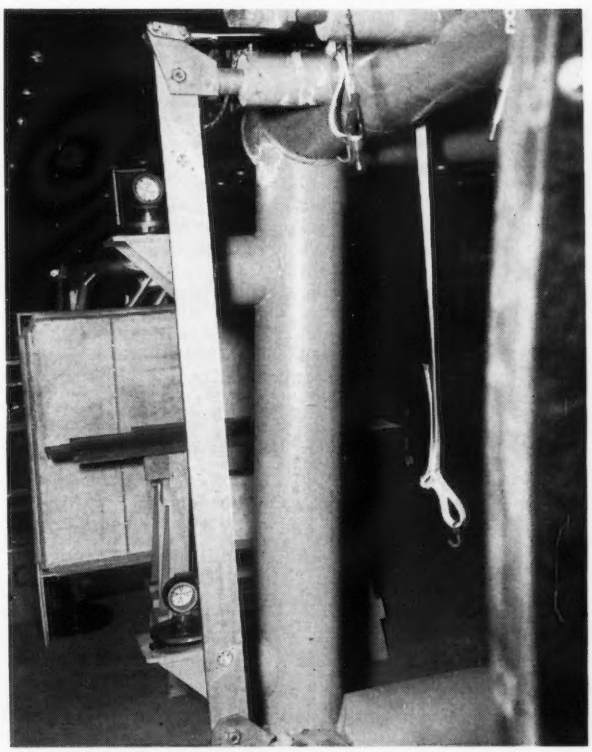


Figure 12
Optical Location Bar

In the completed tool shown in Figure 11 some of the formers have been removed for clarity. The method of attaching the formers can be seen; two threaded pins are used to afford location and locking. This method enables rapid and consistent changes of former board to be made during production.

THE METAL BONDING OF ASSEMBLIES FOR THE CANADAIR CL-28 MARITIME RECONNAISSANCE AIRPLANE†

by J. J. Waller*

Canadair Ltd.

SUMMARY

In the construction of the CL-28 aircraft, there are over 1200 assemblies, large and small, in which metal bonding is used, and the author describes the factors influencing the choice of a bonding adhesive and the equipment to meet the strength and production requirements. He gives a detailed description of the techniques employed, from cleaning the surfaces to be bonded and the application of the adhesive, to the curing process, stressing the need for careful handling and quality control throughout the various stages. He also touches on some of the problems associated with the inspection of bonded assemblies. The protective treatment of bonded assemblies by immersion methods is undesirable and the author describes the brush-on and wipe application methods now used. In conclusion some of the significant advantages to be gained from bonding, as opposed to other methods of fastening, are reviewed.

INTRODUCTION

I would like to begin by taking a moment to say something about the CL-28 airplane. This aircraft, which is somewhat larger than the Douglas DC-7 and the Lockheed Super-G Constellation, is to be used by the Royal Canadian Air Force for anti-submarine work over the coastal waters of Canada. Although it is an adaptation of the Bristol Britannia, we are making so many major changes that it will be hardly recognizable as such when it is completed.

As for the requirements for metal bonding, there will be over 1200 assemblies, many of primary structural importance, to be made using this process. These range in size from a few inches to over thirty feet in length. Some of the problems we have been faced with, because of this large range in sizes, will be described later on in this paper.

ORGANIZATIONAL APPROACH

One of the first matters we had to consider when embarking upon this bonding program, was how to introduce into our production facilities, a process which is so radically different from anything we had used before. This was further complicated by the fact that we had a rather tight engineering release and production schedule to contend with. Co-ordinated decisions had to be made quickly and carried out effectively within our rather large organization. Until certain of these basic decisions had been made and we were well along in the experimental phase of production bonding, we considered that operating through our normal line organization would be too time-consuming since there were so many other problems associated with the overall CL-28 program which had to be explored and settled.

Accordingly, it was decided to introduce bonding as a production process, by means of a committee whose membership consisted of representatives of the various departments in our organization concerned with metal bonding. This committee, which was virtually autonomous, represented Structures and Design Engineering, Plant Engineering, Manufacturing Engineering, Production, Quality Control and Materials and Process Engineering. What this approach meant was that three weeks after the bonding department had been set up, we were able to produce bonded assemblies of specification quality. This elapsed time included that required for equipment and tool proving as well as the training of personnel who had no previous experience in metal bonding operations.

Although we had done a certain amount of laboratory bonding of test specimens before, we learned in the difficult manner that there is a very wide gap between laboratory and production procedures.

SELECTION OF A SUITABLE ADHESIVE

We next had to decide upon the adhesive we should adopt for our use. There were several available in the United States and Canada, one of which was originally developed in the United Kingdom and which is being used there almost exclusively, with apparent success.

Amongst the adhesives available were those suitable for applications subject to the normal temperature range of −65°F. to +180°F., and those for the high temperature range of −65°F. to + 500°F. Our needs were for an adhesive to be used only in the normal temperature range. Also, at the time the decision had to be made, the high temperature adhesives available had not yet been adequately developed for use on a practical basis.

After visiting several airframe manufacturers in the United States and in the United Kingdom, all of whom

†Paper read at the I.A.S./C.A.I. International Meeting in Ottawa, on the 4th November 1955.

*Chief Materials and Process Engineer.

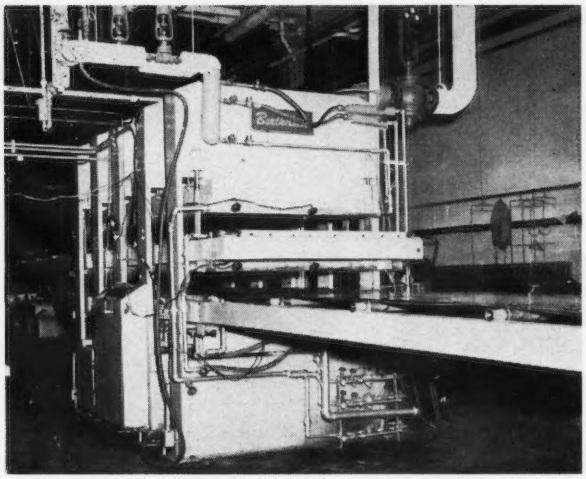


Figure 1
General view of 5′ x 12′ platen press. Two openings.

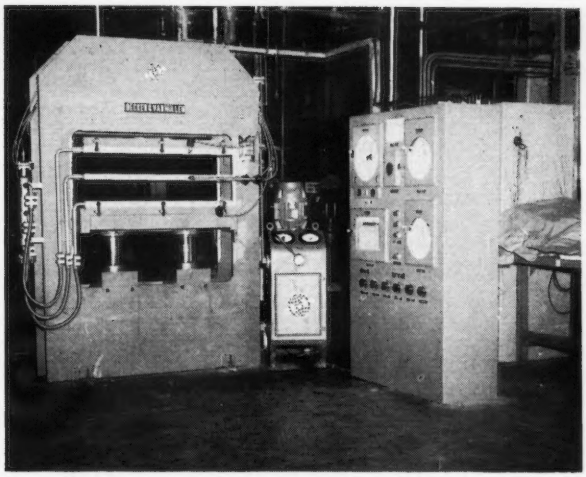


Figure 2
General view of 2′ x 4′ platen press. Two openings.

were doing bonding under production conditions, we consolidated their reactions to the particular adhesives they were using, and selected as the best for our purpose, Bloomingdale Rubber Company's FM-47 tape system adhesive. This is a −65°F. to +180°F. adhesive covered by Specification MIL-A-8331. By means of a special cure, reasonably high mechanical properties can be obtained at 300°F.

Amongst several others, our principal reason for selecting a tape or film-type adhesive was our contention that a better and more consistent quality bond could be obtained than with, for example, a powder-type adhesive.

FM-47 is a two-component adhesive, consisting of a primer and a tape. The primer is composed of a partially polymerized phenolic resin to which has been added a quantity of a vinyl resin. The tape, about 0.015″ thick, consists of a loosely-woven fiberglas cloth impregnated with a material similar in composition to the primer. The function of the glass cloth is that of a vehicle or support for the tape. The cloth contributes very little, if anything, to the strength of the cured adhesive.

The purpose of the vinyl resin in the formulation is to increase the ductility (and the peel strength) of the cured adhesive. Cured phenolic resins, by themselves, are extremely brittle. However, the vinyl resin does lower the shear modulus of the adhesive from approximately 1.5 million psi, to about 0.75 million psi.

SELECTION OF EQUIPMENT

The next phase of our program which had to be investigated was the selection of the equipment necessary for production bonding.

We had to plan for a rather limited rate of production, and since the assemblies to be bonded varied in size from those which are very small to those which are very large, we had to select equipment which would be versatile and at the same time require bonding tools which would be relatively inexpensive to make. We considered the "pants presser" type of tooling, the inflatable-diaphragm type and the integral pressure, heating and holding type as well as many other similar types, to be too expensive for our requirements.

One of the first basic decisions we arrived at was that in general, all flat parts would be bonded in platen presses, and all contoured parts in autoclaves. On this basis, most flat parts would not require any tooling whatsoever, while the tools required for autoclave bonding would be of the light-weight, inexpensive type made generally of sheet metal.

Two platen presses were purchased, each with two openings and platen sizes of 2 feet × 4 feet and 5 feet × 12 feet. (Figures 1 and 2) The platens are heated by steam and cooled by water. Steam was selected in place of electricity as the heating medium, because of the widespread reports received that the latter did not provide a fast heat-up time on an economical basis, nor did electricity provide as good a temperature uniformity as steam.

The pressure for press curing was selected at 200 pounds per square inch.

In regard to the autoclave, it was decided to purchase one unit only (Figure 3) having the working dimensions of 8 feet in diameter and 35 feet in length, so as to accommodate the largest part to be bonded. The maxi-

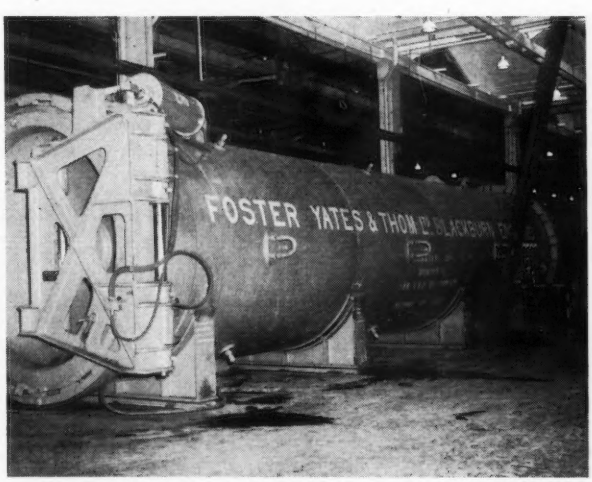


Figure 3
Autoclave.

mum pressure for autoclave bonding was chosen to be 100 psi, as higher pressures would involve a great deal of expense and the safety hazards would be greatly increased.

Heat was to be obtained by means of a steam heat exchanger and a circulating system located inside the autoclave. Although some firms are believed to be still using wet-type autoclaves—that is, the live steam contacts the parts to be bonded—the trend for the past several years has been toward dry units so as to obtain the desired flexibility of temperature and pressure.

The curing temperature selected for both methods of bonding was 310 $\pm$ 10°F. This selection was made so as to obtain the fastest curing time without tending to anneal or soften the aluminum alloy parts being bonded.

Since our own autoclave is just at the stage of being erected, up to the present we have had to use a vulcanizer (Figure 4) located in the plant of a local rubber company.

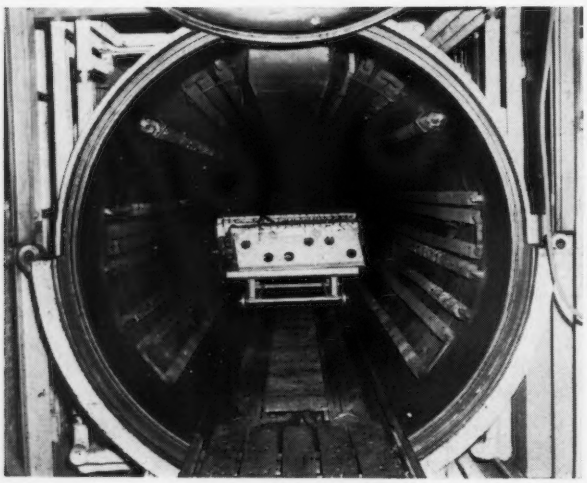


Figure 4
Rubber vulcanizer.

BONDING TOOLS

As mentioned previously, our press tools were held to a very small number, since when bonding a flat part to a flat part, no tools are really necessary. For example, when bonding a spar web reinforcement to the web itself, the detail parts are placed between the platens of the press, separated on each side by a thin sheet of heat resistant rubber and a thin sheet of soft aluminum. We found the soft aluminum sheet to be necessary since at a pressure of 200 pounds per square inch the rubber flows, developing high friction between it and the parts being bonded, and creating a tendency for one of the parts being bonded to shift relative to the other—even when they are tack riveted together—the rivets being sheared.

The instances where tools are required for press bonding are for such items as corrugated assemblies, for example, where only certain areas have to be bonded. Figures 5 to 8 illustrate parts and tools falling into this category.

The tools which are used for autoclave bonding are made of aluminum sheet with the supporting structure made of thin aluminum plate. (Figures 9 and 10) The

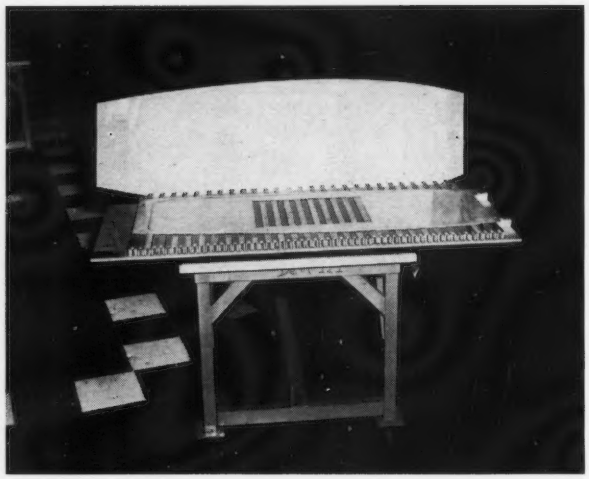


Figure 5
Tooling for corrugation bonding.

Figure 6
Tooling for corrugation bonding.

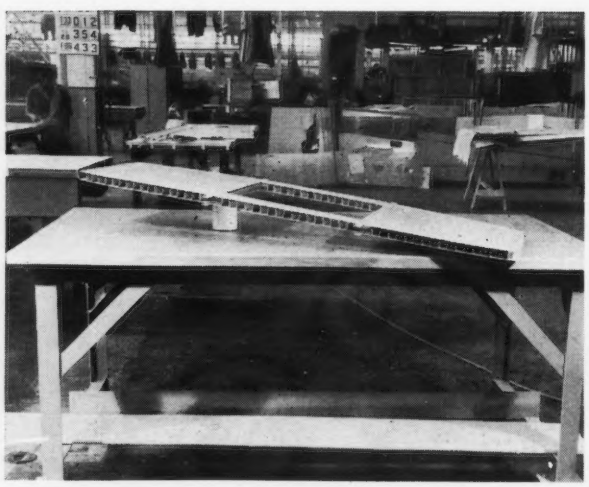


Figure 7
Bonded corrugation assembly.

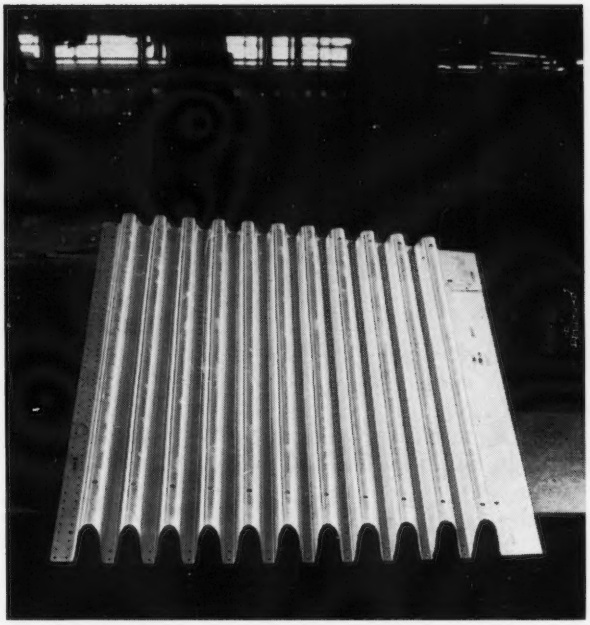


Figure 8
Bonded corrugation assembly.

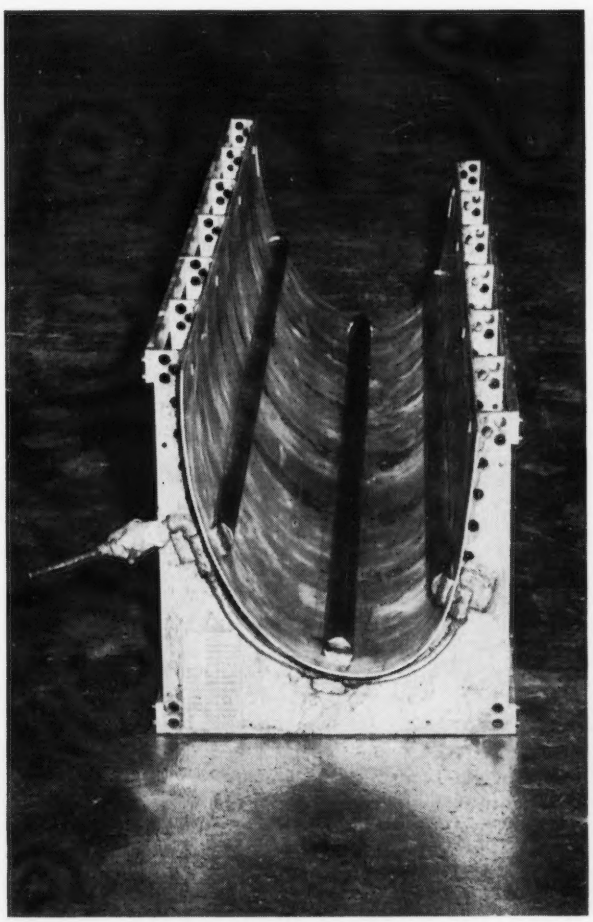


Figure 9
Autoclave bonding tool.

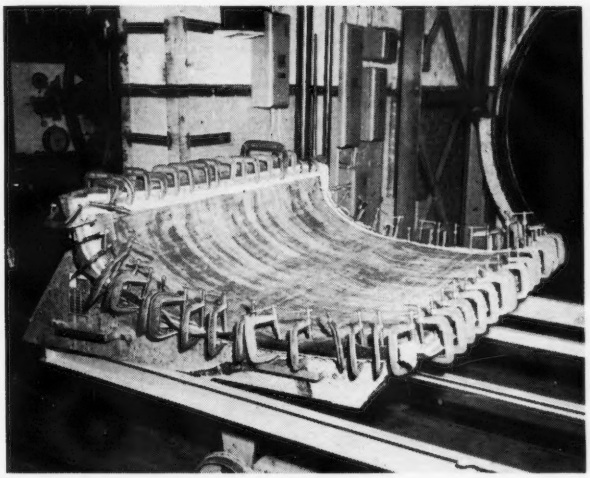


Figure 10
Autoclave bonding tool.

sheet is contoured to the same shape as the assembly being bonded. This is then supported by "ribs" onto a base which, in turn, supports the whole bonding tool. Connections are provided for vacuum lines. The simplicity of this type of tooling is self-evident.

BONDING PRE-TREATMENT OF ALUMINUM ALLOY PARTS

The pre-treatment of aluminum alloy parts to be bonded is a very important phase of the process.

The first stage consists of removing the oil, grease and other soil from the surfaces to be bonded. This can be done in several ways using either or both vapour phase degreasing or alkaline solution degreasing. For reasons of economy and because it lends itself to "production line" methods, we selected the use of an alkaline solution. I will not go into the details of this phase of the pre-treatment since it is a process in general use throughout the industry. There is one problem we have encountered with alkaline cleaning and that is the removal of the alloy identifying inks which the aluminum mills

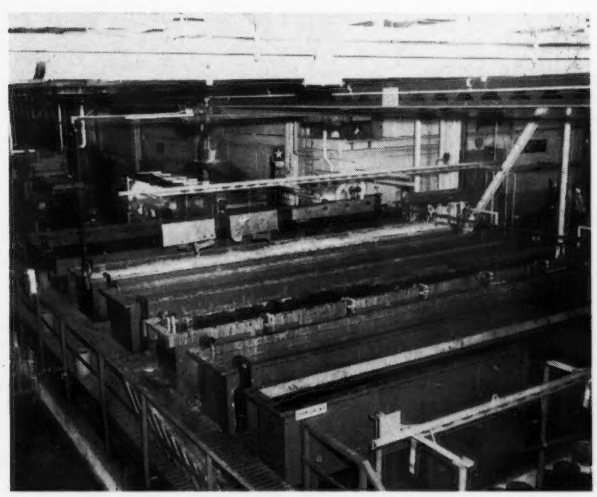


Figure 11
General view of pre-treatment tanks.

use. We purchase our aluminum materials from three different mills and each one uses a different identifying ink. Up to the present time, we have been unable to find an alkaline cleaner which will remove all these inks. Accordingly, material from certain mills has to be hand-wiped with a suitable organic solvent. This is done, when necessary, prior to the alkaline cleaning stage.

The next stage of the process is the rinsing operation. It has been found that the only way of ensuring complete rinsing is by the use of spray rinse tanks instead of the immersion type. This consists of a conventional tank, adequately drained, with rows of spray nozzles running down the length and on each side of the tank.

Perhaps it should be emphasized at this point, that cleanliness of the material to be bonded is of extreme importance throughout the whole process—more so perhaps than in any other process we are using.

The next stage is the etch treatment of the aluminum, in a solution of sodium dichromate and sulphuric acid maintained at a temperature of 145°F. The time of immersion is 10 minutes.

Then comes a cold water spray rinse, followed by blowing the parts dry with a jet of clean, dry compressed air. Strangely enough, the sodium dichromate-sulphuric acid solution is the only one found up to the present time, which will enable the production of consistently high strength bonds. It is strange, because this solution oxidizes and does not deoxidize the surface of the aluminum.

If I may, I would like to digress for a moment to discuss the theoretical aspects of the mechanism of metal bonding, since it is closely associated with the sodium dichromate-sulphuric acid etching of the material to be bonded.

Clad aluminum alloy sheet, when it is received from the mill and cleaned, has a surface contact resistance in the range of 500 to 2500 microhms. A bond made on such a surface has low and inconsistent strength. Now, if this aluminum sheet is deoxidized in a reagent such as hydrofluosilisic acid, it will have a contact resistance in the range of zero to 10 microhms. A bond made with material so treated is also low and inconsistent in strength.

Then, again, when we treat this aluminum in a sodium dichromate and sulphuric acid solution and measure the contact resistance, we find the value to be in the range of 500 to 700 microhms. Bonds made with material so treated have consistently high strengths. The question is "why"?

Firstly, of course, the sodium dichromate-sulphuric acid solution etches the surface of the aluminum and the microscopic "hills and valleys" so developed not only increase appreciably the surface area of the material but also develop a "keying" surface for the adhesive. However, this is generally considered to play only a minor role in the development of high strength bonds.

The oxide on the aluminum material as it is shipped to us by the mill is formed by natural or ordinary atmospheric exposure. It may be considered to be poorly adherent and non-uniform. The oxide formed by the sodium dichromate-sulphuric acid solution, on the other hand, is not only firmly adherent but is also uniform.

The major role in a good bond is played by polar molecules. The aluminum oxide molecule, which is firmly attached to the surface of the etched aluminum,

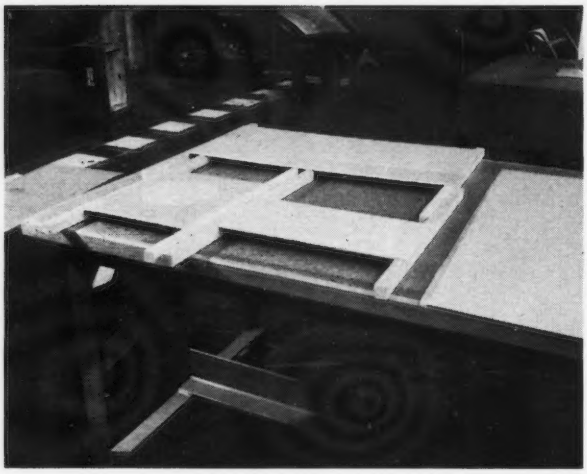


Figure 12
Adhesive in place.

is asymmetric and therefore polar. That is, the electrical charge at one end is farther from the centre of the molecule than the electrical charge at the other. Consequently, the neutralizing effect of one charge by the other is not as pronounced as in the case of a symmetrical molecule. That charge farthest from the centre of a polar molecule will have a high electrical affinity for another molecule particularly of the polar type. In this case, the other polar molecule is the adhesive.

One of the essential characteristics of a good adhesive is that it not only wets thoroughly or comes into intimate contact with the metal being bonded before it is cured, but after curing it must be a molecule having polar characteristics. Adhesives like FM-47 have such characteristics and this wetting action and polar attraction between the molecules of the adhesive and that of the metal surface are chiefly responsible for the high strength bonds obtained.

THE FIT-UP OF PARTS TO BE BONDED

One of the first and important operations to be carried out in bonding work is to determine whether the parts to be bonded fit together properly, so that they achieve the necessary close contact during the curing operation. We have made it a general policy that ordinary hand pressure should bring the detail parts into good contact with one another—in all areas where bonding is to take place.

This requirement for good contact is sometimes difficult to achieve—particularly when one has to deal with complicated shapes such as contoured corrugations.

When the inspector concerned is in doubt as to whether a fit-up is adequate, he uses the dye transfer method for checking. This consists of applying, by brush, to one faying surface, a coating of die-maker's dye, fitting the parts together in the bonding tool and applying vacuum only. If the dye transfer to the other faying surface is complete, then under the normal curing pressure, the requirement for close contact will definitely be achieved.

After the fit-up is checked, the parts are pre-treated in the manner described previously.

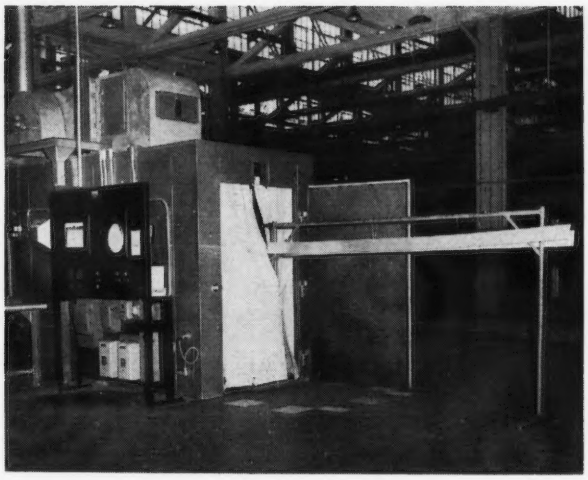


Figure 13
General view of drying oven.

One additional comment on cleanliness: after the parts are pre-treated, they are handled only by personnel wearing clean cotton gloves.

APPLICATION OF ADHESIVE

The faying surfaces of the parts to be bonded are sprayed with adhesive primer to give a dried film thickness of 0.001″ to 0.002″. The adhesive tape is then applied to one faying surface only and rolled firmly into place using a hard rubber roller. (Figure 12) The adhesive is then air-dried for two hours followed by force-drying for one hour at a temperature of 225°F. (Figure 13) This careful drying is essential so as to remove all trace elements of solvent from the adhesive, and thereby avoid poor bonds from being developed as a result of residual solvent evaporating in the glue line during the curing operation.

CURING OF THE ADHESIVE

After the force-drying is completed, thermocouples, made from wire 0.005″ in diameter, are attached to the adhesive tape in preselected areas—so as to ensure that the glue line reaches the required curing temperature.

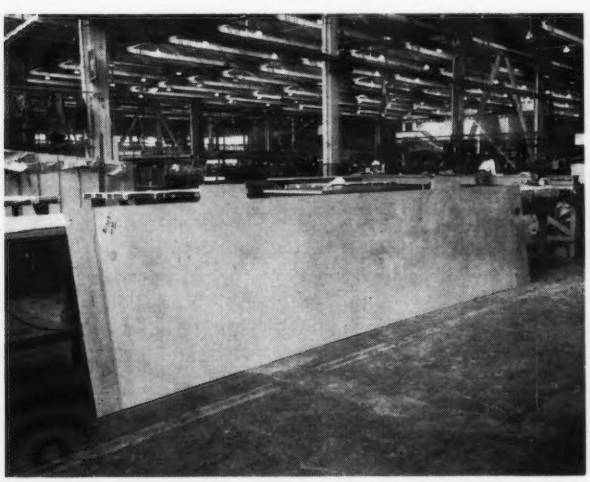


Figure 14
Press-cured bonded assembly.

The parts are then nested together and placed in the bonding tools or directly on the press platen.

In the case of press curing, the heated platens, with the work in place, are brought together under a very low pressure of about 5 psi. The glue line is allowed to come up to 310°F., and allowed to dwell at this temperature for 8 minutes. The press is then opened for 2 minutes.

The purpose of this pre-cure is to start the polymerization of the phenolic resin. During this initial joining together of the molecules, a by-product is water—which, under the conditions, is in the form of a vapour. Opening the press for the two-minute period allows this water vapour to escape and thereby diminishes the tendency for voids in the glue line to develop.

After this pre-cure stage, the press is closed to a bonding area contact of 200 psi, and the adhesive is finally cured at 310°F., for approximately 30 minutes.

After the 30-minute cure, with the 200 psi pressure maintained, the cooling system of the press is turned on. When the glue line has reached approximately 180°F., the press is opened and the bonded parts are removed.

The purpose of cooling down to 180°F., under pressure, is that at 310°F. the cured adhesive has rather low strength. Consequently, handling the parts at this temperature may allow one detail part to shift relative to the other. Also, if there is any tendency for spring-back of the parts to take place, a void could develop since the tensile strength at this temperature is also very poor.

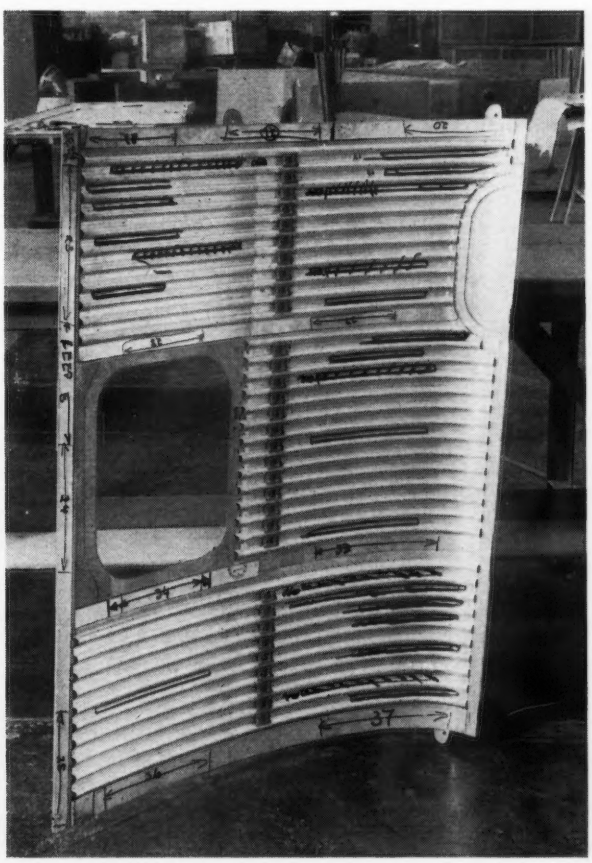


Figure 15
Autoclave-cured bonded assembly.

In autoclave bonding, much the same procedure is followed in curing as in the case of press bonding. The pre-cure as an individual stage is not carried out, since the continually applied vacuum between the rubber blanket and the part draws off the water vapour evolved. The curing pressure used in the autoclave, as mentioned earlier, is only 90-100 psi.

FINISH TREATMENT OF BONDED PARTS

The finish or corrosion protection treatment which has to be applied to metal bonded parts presents somewhat of a problem. It is considered undesirable to treat by immersion methods parts which are bonded, for fear of any reaction which may occur between the solution used in the immersion operation and the adhesive itself or at the interface of the adhesive and the metal. Accordingly, we have had to resort to, up to the present time, brush-on or wipe-on methods.

In the case of clad aluminum metal bonded assemblies, we first wipe the surface clean, using rags and a suitable solvent. Then we wipe-on a phosphoric acid solution which is given a few minutes to react with the aluminum. This is then wiped off with rags and cold water. Finally, a coat of zinc chromate primer is applied.

Bare or non-clad materials are treated with a chemical conversion finish such as alodine or iridite, applied with a brush.

QUALITY CONTROL OF METAL BONDING OPERATIONS

One aspect of metal bonding which has not yet been covered and which is extremely important is that of quality control.

Since by present methods, a metal bonded assembly cannot be examined for good bonding by other than destructive methods, it is extremely important that each phase of the process be carefully and constantly controlled for quality. This not only includes such precautions as frequent chemical analysis of the pre-treatment solutions, testing of incoming shipments of the adhesive, controlling carefully the curing pressure, temperature and time, and liberal use of test specimens processed along with production parts, but also includes such items as watching carefully cleanliness in the bonding department, particularly in the handling of the parts, and keeping flow times between the various stages of the process to an absolute minimum. These are only some of the things which have to be watched.

Quality control is probably more important in metal bonding than in any other process.

INSPECTION OF BONDED ASSEMBLIES

The procedure we are using at the present time for the inspection of bonded assemblies, is tapping with a light weight hammer having an aluminum alloy head. Voids will make themselves evident when a change in the pitch of the noise caused by the tapping is heard. It must be admitted that this is a very unsatisfactory method, particularly since voids in heavy gauge materials are difficult to locate in this way.

Stanford Research Institute along with Convair in Fort Worth has developed a more exact method of distinguishing between good and poor bonds. The equipment is basically the same as the ultrasonic equipment used for the detection of flaws in metal, except that the bond testing equipment functions on an impedance measuring principle. Although we do not yet have such equipment in use in our facilities, I have had the opportunity of examining bonds by this method and found it to give a positive indication. The equipment is known as a Stub or a Stubz meter but is not yet commercially available.

METAL HONEYCOMB ASSEMBLIES

Throughout this paper, no mention of the metal bonding of aluminum honeycomb assemblies has been made. The principles are inherently the same except that lower curing pressures are used so as to avoid crushing the honeycomb.

CONCLUSION

In conclusion, some may wonder whether all this apparent trouble one has to go through to make properly bonded assemblies is worth it or not—particularly in this day of automatic riveting and resistance welding equipment that almost fit in completely with the current philosophy of "automation".

We have wondered about this too, until we discovered that by going to joining methods other than bonding would have cost us approximately 1000 pounds in structural weight. On this basis, metal bonding becomes a necessity and not a process to be considered as a choice between it and some other joining method. Apart from the saving of weight, for certain critical items, bonding will afford a much greater fatigue life than other methods of joining. Also, for high speed aircraft, bonding gives a better surface from aerodynamic considerations.

PROBLEMS FACING AERONAUTICAL RESEARCH IN CANADA

LETTER TO THE SECRETARY

I WOULD like to state that the views on "Problems Facing Aeronautical Research in Canada" appearing in the March 1956 Editorial are expressed as my own and not as those of the National Research Council.

Ottawa — J. LUKASIEWICZ

ENGINEERING TRAINING†

by Professor T. R. Loudon*

The DeHavilland Aircraft of Canada Ltd.

EARLY DAYS

BEFORE discussing Aeronautical Engineering in particular, I propose to trace the evolution of Engineering Training during the past century so that we can see how the present system was arrived at. The original process of becoming an engineer was to article oneself to a recognized practising engineer. You paid for this privilege and also for any tutoring in mathematics and physics you might require. Then after a period which varied from two to four years, you were entitled to do a moderate amount of engineering design, I dare say hoping that your structure had a good chance of standing up.

University Training

Gradually, the idea grew that a University training in mathematics and physics was a much quicker and better way to become an engineer than that of trying to get this training by one's self with or without a tutor. This idea grew quickly in North America; but made progress very slowly abroad. Out of this grew the idea of the Engineering College; and from the beginning it was always understood that these Colleges would merely train students to become engineers. It was the responsibility of Industry to train these candidates in the practice of engineering.

It was a long and tedious battle to get recognition of University Engineering Training; for at that time, these institutions were regarded by many as trade schools. Indeed, many had the idea and still have that any University training other than a Liberal Arts course could hardly be called truly educational.

In those early days, it was necessary to show that there was a demand for these University trained engineers. A great deal of emphasis was placed upon training in surveying and draughting room procedure. The growth of these institutions and their final acceptance as training schools was founded largely upon the growth of railroad building and the surveying of the open spaces of Canada. The draughting room training also supplied manufacturing and structural fabricating companies with draughtsmen, no other source being available at that time.

Originally, all engineering which was not military was called civil engineering. This is the basic department from which all others have developed. The demand for specialization began largely in the 1890's and resulted eventually in Departments of Mining, Mechanical, Electrical, Chemical Engineering etc.

There is a curious fact regarding one branch of civil engineering which is of great importance to our present discussion. Surveying is one branch of engineering in which certain theoretical and supervised practical standards have been laid down which must be met before one can carry on as a legally recognized surveyor. The Ontario Land Surveyors (O.L.S.) and Dominion Land Surveyors (D.L.S.) hold examinations and demand a certain period of practical experience under a recognized surveyor before the degrees of either O.L.S. or D.L.S. are granted. An Engineering degree does give exemption from some of the written examinations but not from any portion of the practical work. In other words, the Surveying Associations demand supervised practical experience and provide the means for getting it.

The Professional Engineers' Associations in the various Provinces are not as strict in their requirements for practical experience. In Ontario for instance, a University graduate must have one year of practical experience before being admitted to membership and being recognized as legally allowed to represent himself as a practising engineer. The practical experience, of course, must be with a well recognized source; but be that as it may, ordinarily practical experience is not subject to very rigid supervision. But how can it be otherwise when Industry as a whole has very few training schemes?

Practical Experience

There are some exceptions to the statement above. A few manufacturing firms have had training schemes for a number of years. Undergraduates are encouraged to come into these schemes during their summer vacations; and also, the young graduate is first put through some training before being allocated to a position in the firm. In this way, both the employer and the employee are enabled to find the most suitable place in the organization to the satisfaction of both parties. A great deal of experience, however, is not at all properly organized for either the undergraduate or graduate. It depends largely on his own power of observation as to how much practical experience he does get. The Engineering Colleges also do demand in some courses that

†Paper read before the Ottawa and Toronto Branches of the C.A.I. on the 11th January and 14th February, 1956, respectively.
*Assistant to Chief Engineer.

an undergraduate must put in a certain number of hours in practical work; but the organization of this is left pretty much to chance.

DEVELOPMENT OF UNIVERSITY TRAINING

There was a large up-surge in the attendance at Engineering Colleges at the beginning of this century. The value of the Engineering graduate had been established; and in all this, credit must go to the Engineering Colleges of North America for establishing a method of training whereby the student devoted all his time to University work for seven or eight months and was then free to get practical experience for the remaining portion of the year, a large portion of which was during the summer. Any scheme which suggests giving a University training to individuals who are actively engaged in practical apprentice work is at least 30 years out of date.

Many changes have come about in the courses offered since the early days. The emphasis on draughting and surveying has disappeared. An engineer must be able to make a drawing but should not be called upon to spend his time at too much of this as it can be done better by expert draughtsmen with Technical School training. As far as surveying is concerned, it is a question whether a great deal of elementary surveying theory is of University calibre.

During the growth of these Engineering Colleges, there has always been pressure from Industry demanding that more and more practical engineering be taught in the Universities thereby relieving Industry of some of its responsibility to teach the practice of engineering. This has resulted in the establishment of some laboratories in which the experiments give a familiarity with some industrial processes; and a certain amount of design procedure has also been introduced into courses from time to time. Some of the Engineering Colleges originally had machine shops in which students were instructed in the operation of machine tools; but this procedure has long since been out of date. A student can get far more experience in an actual machine shop in a short time than in a disconnected laboratory course during a University session of 24 weeks.

My own opinion about some laboratories which require written reports is that great caution should be exercised to see that the value of this work is not over emphasized. I have actually seen students spending several evenings a week during the whole session writing up these reports with practically no time left in which to get up the lecture work! The cramming necessary later on to get up the neglected lecture instruction leads to mediocrity.

English

There are those who claim that writing laboratory reports is good training in English composition. Any writing is training if one knows some of the rules of composition; but the filling in of data hardly comes under this heading; and it is hoped that the day of writing elaborate descriptions of apparatus has passed.

This brings us to a point of great importance – the writing of concise reports. There has been for some time an insistent demand that engineers be taught in the University to write English, and this has brought about the raising of University entrance requirements in English. Many candidates formerly seemed to look upon this subject as a necessary evil and merely did enough work to get a credit pass mark. Actually the insistence should be placed upon better teaching of the subject at the High School level. (See Appendix)

Cultural Subjects

Another outcome of the growth of Engineering Training is the inclusion of subjects on economics, world history and philosophy in the curriculum. Indeed, in some institutions a very large percentage of time (20%) is devoted to these cultural subjects. It is very well recognized, at last, that the engineer must compete in the social world with the other professions; not merely as a technically trained individual but as an educated citizen fully cognizant of his national responsibilities.

Lawyers and doctors by training and tradition observe the social amenities and prosper thereby. I do not wish to infer that the only reason for observing these forms is to gain a more lucrative living; that is something which is a by-product. Man becomes a warped individual if he pursues just one of his intellectual gifts. The exercise of all this intellectual ability in as many fields of human endeavour as possible raises the level of his usefulness in his chosen activity.

Professional Status

G. E. Morse, Vice-President Industrial Relations of Minneapolis Honeywell Regulator Co. made a statement at the recent 21st Annual Meeting of the National Society of Professional Engineers' of the U.S. in a conference on *The Responsibility of Industry and the Engineer* to the effect that: "Engineers who want the status and pay of professionals must act, work and live like professionals. The key to success is not only technical competence, but also social and personal competence".

N. W. Dougherty, Dean of Engineering, University of Tennessee and President of the American Society of Engineering Education at this same meeting decried the separation of Management from the professional engineer and said further on the subject that: "It is time that Colleges taught their students the difference between a skilled workman and a professional engineer. The Colleges must join with industry in creating a good atmosphere in which professionals can grow. Young people come to High School and College with high aspirations for the future. It is certainly a let down for them to enter Industry and find they are just some other employees".

Carl A. Frische, Vice-president for Operations, Sperry Gyroscope Co. summed up Engineering Management's responsibility with:

(1) make certain that engineers understand what is expected of them;
(2) review progress at regular intervals;
(3) make the engineer feel that his work is worthwhile and is being recognized;
(4) create a feeling on the part of the engineer that he is being treated fairly in comparison with other engineers.

These opinions show how the thinking on engineering professional status has changed in the last fifty years. Item (2) above implies that Management has a responsibility to see that adequate salaries are paid to engineers.

ENTRANCE STANDARDS

A very disturbing factor began to emerge during the 1930's in Canada, and is now of great national importance as we try to find more engineers. The percentage of failures in the first year of Engineering Colleges has risen to as high as 30% of the registration. This represents a loss of many thousands of dollars to the citizens of Canada who pay a large portion of the cost of education in Universities; and I wish to emphasize the fact that this is also a terrible wastage of potential technical personnel. Many theories have been put forward as to the cause. At the University of Toronto formerly, there was no particular standard of entrance beyond passing all subjects of Grade XIII. This was changed to a point system; First Class Honours counting 1 point, Second Class 2 points, Third Class 3 points and a Credit 4 points. The total was not to be greater than 26 which for the nine subjects concerned is an average of a little better than Third Class honours. This has been changed to demanding an average of 64% on all nine papers for the ordinary Engineering courses, Aeronautical Engineering and Engineering Physics courses demanding First Class honours in mathematics and physics. The percentage of failures still continues to be high!

In many cases, the student has not cultivated a habit of work before coming to the University. The idea that in the evening he has to do at least three hours studying on an average of five nights a week is a big shock to many who have been accustomed to doing very little study at High School. Also, as you know, it is quite feasible for a student to take two to three years to get a few subjects at a time for Grade XIII; but when he comes to the University, he has to pass nine or ten examinations at one time and he has not the capacity to do so. A University education is looked upon by too many as a right. It is not; it is a privilege only for those who will work for it and accept its responsibilities.

There are some who say that I.Q. tests should be held to determine who are bright enough to enter the University. Wisely administered, some interesting information could be obtained. I have had some experience with terrible mistakes which might have been made had the student taken the advice based on these tests. In one case, a student was told that he had absolutely no capacity to become an aeronautical engineer. I asked the student what he wanted to do. He told me he had looked forward to getting into the Aeronautical Industry for years. I told him to go ahead, which he did and is doing well in the Industry. Another case I remember is that of a student who forwarded to the Council at U. of T. after writing his examinations a letter from an I.Q. testing firm which said that the candidate was unusually bright and had great capacity for work. He failed in every subject!

TEACHING

There is no doubt that a small part of the cause of the high failure rate in the first year of University courses is due to insufficient competent staff to deal with the large numbers. Classes of 100 to 200 for a lecturer to deal with does not allow any individual attention to be given. A class should not be over thirty for good results, and in the best U.S. Colleges this is about the allowable limit. I would also emphasize the fact, as my own opinion, that there is a great difference between lecturing and teaching. Lecturing merely requires the ability to stand up and talk. Teaching requires qualities of sympathy with the student and a wish to explain things properly from a background of practical experience; and also to stimulate the imagination from actual experience. It should never be forgotten that the first function of a School or University is to teach. Are we exercising enough care in choosing our teaching staff in our Schools and Colleges?

There has been an opinion of long standing that engineers should teach Engineering courses. Unfortunately, it has been difficult to get engineers who wish to teach mathematics. Also, it looks like an inefficient method to have a highly skilled staff of mathematicians for Arts courses who are not available for teaching engineers. Where this argument is faulty is that Engineering students quite rightly wish to see how the subject is applied to engineering problems. It is all very well to talk about some interesting theory using symbolic expressions; but to the student who is going out into life to apply his training, he must be shown some practical value of the subject.

TECHNICAL INSTITUTES

But even if all these difficulties were overcome, there is no doubt that there are many who come to the Universities who should be diverted into the Technical Institutes to be trained as technologists. There should be more of these Institutes in Canada as the work performed by these technologists is of vital importance.

TECHNICAL SCHOOL "DROP-OUTS"

I have been investigating the cause of "drop outs" in the Technical Schools. In Toronto 23.8% of the total registration "drop out" before final graduation at Grade XIII level, mostly at Grade IX and X. The peak "drop out" occurs at the age of 16 which is the legal limit up to which attendance is compulsory. The chief reason given by those investigating the reasons is "Lack of Application"; although a number of students say they "drop out" from "Lack of Interest". In other words, a large number of these "drop outs" is due to lack of the wish to work at studies. There are other reasons such as "Lack of Ability" and "Financial Difficulty", this last reason giving a rather confused picture in which the investigators state that even if financial help were furnished in a large number of cases, it is doubtful whether the students' abilities were high enough to allow them to graduate. The interesting point about these "drop outs" is that 46% had I.Q.'s from 100 to 110, indicating that they had the mental ability to continue their studies. I feel that great effort should be made to salvage this wastage.

But, you must keep in mind that you are competing against high wages for skilled and unskilled labour. The young man is not very much impressed with more than the wages which will enable him to buy an automobile for himself. A television interview lately with a number of High School students who had left as soon as they reached 16 years of age, revealed a very low level of objective in life. They left so that they could buy an

automobile and go to movies or dance halls every night as the desired daily routine. The parents in their interviews could not have cared less! This is the apathy and ignorance against which you are competing for professional engineers and technologists.

AERONAUTICAL ENGINEERING

When we turn to the Aeronautical Industry in Canada, we find a condition which is unique. The growth of the size and complexity of aircraft in a comparatively short period of time has been phenomenal. This has resulted in a great demand for technical personnel of all types. It would be very easy for me to say: "I told you so!" For many years, those of little faith and imagination have held back the training of aeronautical engineers and technologists in Canada; and Industry has not been entirely blameless. Commercial flying is here to stay and will increase in capacity and speed of flight. Anyone who has no faith in the permanence of the Industry should get out of it as quickly as possible. There is no place in the Industry for people lacking in the ability to evaluate the trend of history.

But what is the situation and what can be done about it? It has seemed to me that a great deal of confusion exists because the limits of the problems have not been defined properly. It should be recognized that the term "engineering" covers a wide field of endeavour from design to production; and any scheme of training should take this into account. For the purpose of this discussion, I propose to divide the field into three parts; craftsmen, technologists and specialist aeronautical engineers of all types.

Craftsmen

The training of craftsmen by apprentice schemes is extremely important if future supervision is to be carried out by well trained personnel instead of depending upon the hit and miss method of seniority in the plant. It may be difficult to get young men to accept this type of training as the wages during training are not likely to be as high as those they can obtain for ordinary labour in some industries. Whatever training is offered, it should be under the supervision of skilled craftsmen; but the responsibility for running the scheme must be in the hands of Management. This can be accomplished, I feel, by the proper approach. There are in existence, certain Provincial Training Schemes which have had a fair measure of success. It may be that "drop outs" from Technical Schools can be found in the plants. Some of these have undoubtedly left schools not from any necessity at home, but to make money and get out of the chore of studying. Many of these "drop outs" soon see the limitations of their work and often wish they had remained in school. These should be encouraged to take apprentice training with the objective that they can go on to train as technologists or even go back to school. Any training scheme should always aim at stimulating the imagination of the candidate.

I do not propose to spend time on this phase of training. It could take up the whole paper. I merely point out that it has been very difficult to deal with Unions on this subject.

Technologists

When we consider the Engineering Staff, it is difficult to draw a hard and fast line between the requirements for some of the departments of aeronautical engineering. There is a large amount of very important work which is done by technologists. Indeed, it cannot be emphasized too strongly how important this group of engineers is in the aircraft industry. By and large, this group does not qualify for professional engineering standing; although this can be obtained by self study and assisted training schemes. Due to the negative attitude of many toward the Aircraft Industry as to its permanence, there has been great difficulty in getting enough technologists in Canada. It has been necessary to recruit a large number from other countries, mostly from England and Europe; and we have been very fortunate in the fine type of new citizens who have come to our Aviation Industry.

One great difference between these last mentioned technologists and our Canadians is that generally the former have received a good practical training in the shop. Young Canadian technologists receive a good general training in the Technical Schools; but they are badly deficient in practical shop procedure. The training in our Technical Schools is excellent; but once students graduate and are employed, there is sometimes very little opportunity to get real shop experience. The foreign technologists during their school training and during the so called holiday periods *must* get training in certain definitely laid down shop practices such as machine tool work, welding etc., and they must produce certificates from employers stating how much practical experience has been obtained. The result of this is that in many cases these technologists can give very valuable suggestions on design and production methods.

The point I wish to make is that in Canada in our training of technologists, Industry must see to it that during their High School or Technical School summer holidays opportunity is given for properly supervised practical training. In doing this it must be kept in mind that it may be necessary to pay these personnel more than their present worth in order to compete with the present highly paid unskilled labour. Lecture courses should also be arranged for technologists after permanent employment so as to increase their technical knowledge and outlook on practical procedure.

Professional Engineers

Finally, when we come to deal with providing professional engineers, the problem becomes somewhat complex again. There are many types of professional engineers employed today in an aircraft manufacturing firm such as civil, mechanical, electrical, chemical, metallurgical and aeronautical engineers. The Industry has developed so that the services of all types of professional engineers are required. These are the professional engineers who carry the burden of design and production, sometimes at the administrative level. They also constitute the supervisory staff of the technologists.

But what I wish to speak about particularly is the specialist aeronautical engineer. These should be the types from which creative engineers come. Their university training must be the very best available in mathematics and science with enough related aeronautical subjects to give them some idea of the nature of aviation. Again,

I point out that there is a continual demand from Industry for more and more of engineering practice to be given by the University. I am speaking from my own experience and that of many others in the United States.

There are many Technical Institutes sometimes called Colleges in the United States which turn out very excellent detail lay out draughtsmen with a sufficient amount of mathematics to enable them to understand what they are doing. These cases are continually pointed out by Industry; and the Universities in Canada are asked why they can't do the same thing. The Universities could do this; but only by lowering the standard of basic training thereby making it impossible for the candidates to take post graduate work.

Post Graduate Work

It has become increasingly evident that post graduate training is absolutely necessary for all personnel dealing with certain of the problems of the present day high speed aircraft with their power plants and multitude of electronic devices. These then are what I term the specialist aeronautical engineers. Sometimes the graduate student is able to finance his post graduate years; but more often, he is prevented from doing this and has to go to work in Industry. There is a simple solution to this. In 1954 the writer arranged for the de Havilland Aircraft of Canada to take on graduates in Aeronautical Engineering and allow them to take post graduate work while on the pay roll. This has been very successful so far and has resulted in others falling in line with this idea. The lecture work is given after working hours and the successful candidates in the examinations in 1956 will be given leave of absence to complete their course in full attendance at the University with substantial salary included.

This brings out an interesting point which should be clarified. For some time past there has been pressure from personnel in Industry to have post graduate degree courses given in the evenings after work hours. Then when faced with University regulations which demand a full time attendance for a complete academic session, the employer will not grant this time with any salary attached. The question raised is always: "Are the lectures not sufficient? A thesis can be written while continuing work so why the full time attendance?" The whole point of the post graduate course is entirely missed. Actually, the purpose of a post graduate course is to work under the supervision of competent staff to increase one's expert knowledge; and the candidate must show a capability for original thinking, in other words be a creative engineer before being granted his advanced degree, and this can only be done by full time attendance.

The Institute of Aerophysics at the University of Toronto turned out 16 Ph.D. candidates up to 1954 of which 50% have gone to the United States, one to Canadian Industry and the remainder to the N.R.C. and Research Establishments; a poor record for the large expenditure of Canadian money and the future of our Canadian Design Industry. These losses are largely due to the high salaries paid in the United States and also the indifference of Canadian Industry to using highly trained specialists.

Practical Experience

And now I wish to emphasize the point again that these specialist aeronautical engineers in Canada have been given practically no opportunity to obtain any practical experience during the vacations between sessions of their four year course. The result is that they find themselves with a first class basic training but at a disadvantage compared with many who have received practical training elsewhere. This would not be so if the Aviation Industry would take them on as undergraduates and train them. There have been at least two stumbling blocks in doing this. Firms do not like to have short term employees on their hands as it upsets their routine. Also Trade Unions have resisted any attempt to introduce these young students into their work arguing that some unemployed man should be taken on first.

Each firm should have a definite course of practical instruction with lectures on the organization and responsibilities of each department to give some ideas as to how the company is run. Properly explained to Labour, it can be shown that it is to their advantage in the long run to have these young men trained in practical shop work.

Any idea that this practical work can be sandwiched in during the University session is out of date. The intensive training in mathematics and science requires a full day and evening work for this specialist training.

Much of what I have said about the specialist applies to the training of technologists. Young men in the Technical Schools can be taken on for summer training. If they graduate with Grade XIII standing they should be encouraged to go to the University; but, if they do not and come back to the plant they should be enrolled in a further training scheme.

PROPER EMPLOYMENT

And now may I speak about a point which has caused some concern. We hear continually about the shortage of engineers in our Industry; but let me ask the question, *Are all engineers properly employed?* There have been quite a few letters in the literature asking this question. Are young men, after a few years of familiarization with the Industry and with first class basic training, being misemployed under personnel who give no encouragement and under whom they cannot possibly advance in their ideas? If any of this exists, rest assured that it very soon becomes known to young men in Universities and other training centres.

Now and then one hears that young graduates from Universities have an exaggerated sense of their value and act accordingly. This is a curious statement. The writer engaged for many years in private consulting practice and has employed many young graduates, and he never came across one case such as this. But of course, our firm always took great pains to teach our young men the practice of engineering. Is the Aviation Industry seeing to it that those under whom young men work are capable of doing this and are they doing it?

One branch of our Aviation Industry, the Armed Services, could well reconsider their policy of posting their highly trained technical personnel around the country thereby shattering any idea of building up competent research and creative facilities. It is not enough

to say that this is necessary to train personnel for promotion by seeing how all departments operate. I recognize that the first duty of the Armed Services is to train for war service. But, young men with creative ability should be kept where they can use that ability and receive promotion in that capacity. The number of personnel involved would not be large in any event. I was surprised to see lately that the same opinion has been expressed by Sir Roy Fedden in England in his Address to the Institute of Production Engineers.

OPPORTUNITIES

If we wish more students to go into 'Science and Engineering and pass their examinations, we should see to it that these young people have their imaginations stimulated at an early date in their life about the possibilities in Science and Engineering. This should not be left to rumour and to people who know little or nothing about these opportunities. You say, how can this be done? By interested individuals and organizations going to school boards and demanding that students be taught to work; and that illustrated talks be given to students by competent lecturers on scientific subjects. Also T.V. which has a terrific impact on young people should be used to stimulate interest. Engineering Societies can also do a great deal. The C.A.I. already has begun a campaign and will have committees in the various centres to stimulate interest and training.

INDUSTRY TRAINING

Finally: The Aviation Industry must undertake to establish training schools with definite routines which can be advertised among the centres of supply of manpower. It is not enough to start a scheme every now and then when some candidates appear. In other words, firms should have definite Engineering Schools in which proper practical and if necessary some theoretical training can be given. These schools should provide training schemes for all three levels, craftsmen, technologists and professional engineers.

Only the Aviation Industry can teach the practice of engineering as it applies to that Industry.

APPENDIX

EDUCATIONAL SYSTEMS

In order to help the reader to understand the differences between High Schools, Technical Schools and Technical Institutes, the following explanations are made:

High Schools prepare students to write University Matriculation examinations. This course normally takes five years to complete, the average age of students at the finish of the course being 18 years.

Technical Schools offer courses directed toward practical training for entry into Industry; but it is also possible to prepare for the University Matriculation examinations taking five years. The average age at the end of the five year course is 19 years. Students drop out and go into Industry at various stages.

Technical Institutes give courses which train personnel for Industry at a more advanced level than the Technical Schools. The level of basic mathematics and science in the courses is equivalent to about one and a half years of University Engineering courses. The lengths of the courses vary depending upon the content, some taking three years to complete. The age group of these students varies a great deal, some students coming from High Schools and Technical Schools, others coming from Industry.

T.C.A.'s VISCOUNT OPERATION†

by B. W. Torell*

Trans-Canada Air Lines

THE subject of this paper, Trans-Canada Air Lines' Viscount aircraft and our experiences with it in actual airline operation, is too wide to permit much detail. However, I will endeavour to point out what I consider to be the highlights of this story.

WHY THE VISCOUNT WAS PICKED

Several years ago it became evident that T.C.A. would need an airplane for intercity operation, to supplement its DC-3 fleet. An investigation into available aircraft quickly narrowed the choice down to two, an American two-engine aircraft and the Vickers Viscount. The overall technical comparison showed little difference between the two types of aircraft in so far as the various

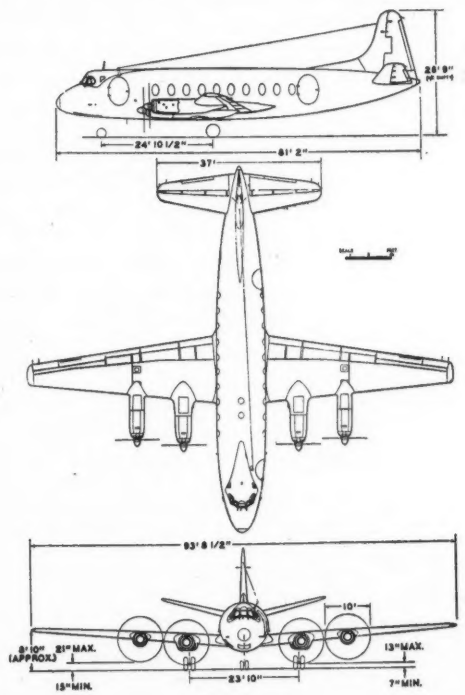


Figure 1
General dimensions: Viscount 724

AIRCRAFT PROPORTIONS:	
Overall Span	93′– 8″
Overall Length	81′– 2″
Height Over Empennage	26′– 9″
Stabilizer	35′– 6″
Track (center to center oleos)	23′–10″
Main Tire Size	36 x 10.75 x 16.5
Nose Tire Size	24 x 7.25 x 12
Diameter of Propeller Disc	10′– 0″
Minimum Ground Clearance Outboard Prop Disc	21″
Maximum Fuselage Diameter	10′– 8″
Maximum Cabin Differential Pressure	6.5 psi
Height of Door Opening	6′– 2″
WEIGHTS	
Operational Weight Empty (includes fuel and oil)	38,000 lb
Maximum Weight with Zero Fuel and Oil	49,000 lb
Maximum Take-Off (sea level)	60,000 lb
Maximum Landing Weight	54,000 lb
LOADING	
Wing Loading at Maximum Take-Off Weight	62.3 lb/sq ft
Power Loading	10.7 lb/bhp
PERFORMANCE	
Cruise Speed (TAS) at 16,000 ft. at 56,000 lb gross weight	278 knots (320 mph)
Fuel consumption at above conditions	9.34 lb per nautical mile

Figure 2
General dimensions and performance: Viscount 724

factors of performance were concerned. The Viscount was chosen then because the lower noise and vibration level of this airplane would provide additional passenger appeal and the fact that it had four engines instead of two which gave it an edge, in our opinion, from a safety point of view. In addition, the Vickers Company were responsive to our needs and incorporated in our aircraft some 250 changes which we requested — to more nearly suit this airplane to our particular operating conditions on the North American continent.

GENERAL DESCRIPTION

There, in a nutshell, is the background of our Model 724 Vickers Viscount, shown in Figure 1. This aircraft is a four engine metal, low wing monoplane. It is powered by four Rolls-Royce Dart 506 gas turbine engines.

Figure 2 shows some of the dimensional, statistical, weight and performance figures for this aircraft. The

†Paper read before the Vancouver Branch of the C.A.I. on the 13th December, 1955.

*Supervisor of Engineering.

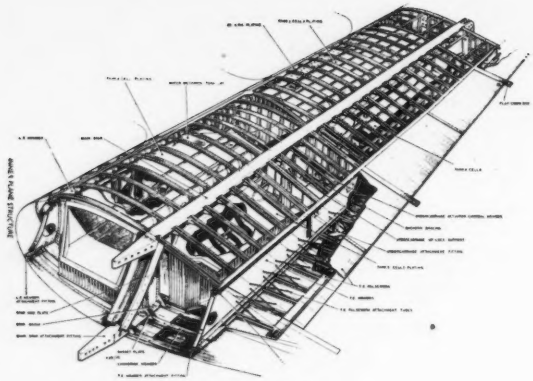


Figure 3
Inner plane structure

Viscount looks like a conventional type of aircraft, the main difference, of course, being in the power plant. There are a number of features, however, in this aircraft that you may find interesting and I would like to mention them briefly.

The Viscount wing structure deserves some comment as it varies from the normal North American aircraft manufacturing practice in that it has a single main spar, as you will note in Figure 3. There are the leading and trailing edge spanwise shear beams and a series of closely spaced cordwise formers but no spanwise stringers. The elevators, rudders and ailerons are operated by push-pull control rods rather than by cables as is the normal North American practice. This has eliminated the difficulties we have with cable tension in our other aircraft as a result of operating into greatly varying temperatures.

There is a stall warning device incorporated on the pilot's control column which warns the pilot of an impending stall.

There are three double slotted flaps electrically operated at the trailing of each main plane. These are automatically operated from the 47° position to the 43° position in the event of a balked landing as a result of the application of full throttle.

FUEL SYSTEM

The fuel system, as shown in Figure 4, consists of 20 crash resistant rubberized nylon fabric tanks, making up four tank systems, one tank for each engine, with normal cross feeds. All the tanks can be filled from the top of the wing or from two points on the lower surface of each wing. This pressure refueling system is equipped with a device to shut off fuel automatically when the tanks are full.

Fuel to the engine is filtered through a 25 micron filter. In order to protect the fuel from freezing at the filter, fuel is heated downstream of the filter by a heat exchanger which is fed hot air from the second stage engine compressor diffuser ring. The hot air is controlled by a pressure switch. If the drop in fuel pressure across the filter exceeds 3 psi, hot air is automatically directed through the heat exchanger.

WATER-METHANOL SYSTEM

There is a water-methanol system installed in the Viscount to restore full engine power at take-off and

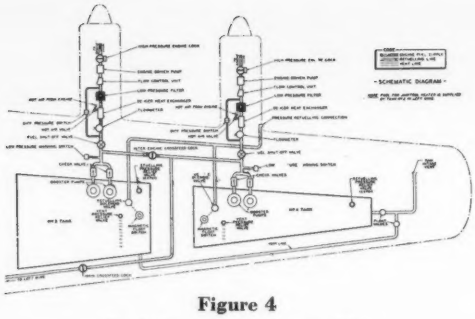


Figure 4
Fuel System: Viscount 724

balked landings when the outside air temperature is above normal (ISA + 10°C.). This system cuts off automatically as power is reduced during the climb.

CRASH EMERGENCY SYSTEM

One of the interesting features of this airplane is the automatic crash emergency system. The system is operated by two inertia switches, set to close under a 3 g impact, and six frangible crash switches, located in vulnerable spots on the aircraft structure, which will close under a crushing load. These are connected into two circuits, each circuit consisting of an inertia and three frangible switches. Any switch in each set will operate a relay and two relays must be operated to complete the circuit to the crash relays. When the crash relays are tripped, they (1) close the water-methanol cocks, (2) energize the heater and fire extinguishers circuits, (3) disconnect the battery from the main bus, and (4) energize the emergency relay which connects the battery to the emergency bus.

DE-ICING SYSTEMS

There are three major de-icing systems installed in the Viscount – a thermal system for the airframe and the engine low pressure fuel filters, fluid and electro-thermal for the cockpit windshield and electro-thermal for the propeller spinners and engine air intakes. Hot air is provided for the airframe de-icing system from two heat exchangers located in the path of the two inboard engines exhaust gas, as shown in Figure 5.

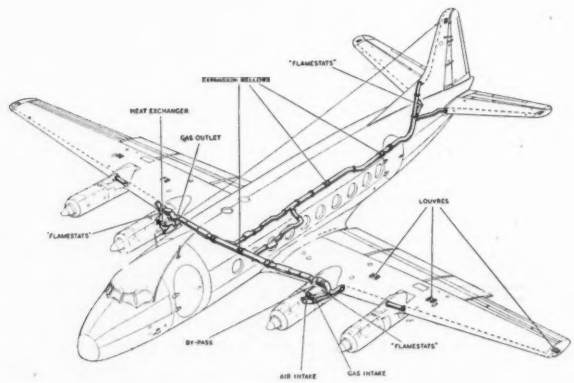


Figure 5
Thermal De-icing System

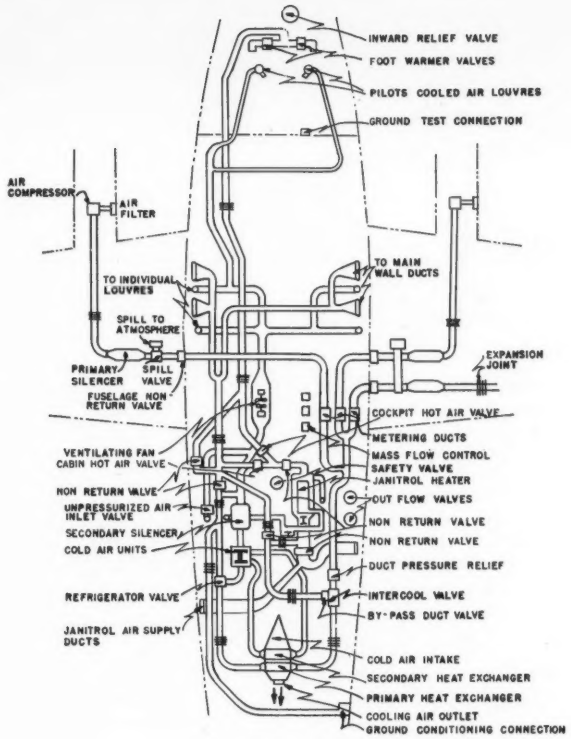


Figure 6
Viscount Airconditioning and Pressurization System

AIR CONDITIONING AND PRESSURIZATION SYSTEM

The air conditioning and pressurization system contains a mixture of AiResearch and Teddington Control units. It is schematically outlined in Figure 6 which may look, at first glance, like a plate of worms. Three engine-driven root type blowers provide air at a total rate of approximately 75 lb/min at 20,000 ft for pressurization. The system will operate to a differential pressure of 6.5 psi which maintains sea level conditions up to an aircraft altitude of 15,000 ft. In the interest of providing a fuselage with a higher fatigue life, we are arbitrarily reducing the maximum differential to 5.46 lb which is identical to our Constellation aircraft.

Cabin and cockpit heat is obtained by choking the flow from the cabin supercharger. When additional heat is required, especially on the ground, a 200,000 btu Janitrol heater is automatically introduced into the system.

OPERATING PERFORMANCE

So much for a brief description of the Viscount aircraft and now for some data on the actual performance of the aircraft in T.C.A.'s operation.

We are presently operating 14 Viscount aircraft and we have a number more on order.

Our Flight Operations Department personnel appear to be quite enthusiastic over the Viscount. No trouble has been experienced by them in converting pilots to the Viscount aircraft from our other types of aircraft. The pilot conversion training consists of a two weeks ground school course and an average of 15 hours flying. The pilot's job on this aircraft is generally simpler than on some other types of modern aircraft, as shown by the reduction in the number of controls, switches, etc., that he must monitor, illustrated in Table 1. In addition, the aircraft contains various devices to reduce the amount of concentration necessary by the pilot such as the Maxaret anti-skid device which prevents wheel skid and provides maximum deceleration regardless of how severely the pilots apply the brakes.

The engine starting cycle is automatically controlled once actuated by the pilot and is not susceptible to technique, as in the case of piston engines. The engine requires no warm up period prior to take-off and the cockpit check can be done during taxi to the take-off position.

If the outside air temperature is above standard, it is necessary to reduce fuel flow by a trimmer control to prevent exceeding turbine inlet temperatures. Water-methanol must also be used in this situation to provide full take-off power.

There is a device that automatically feathers an engine in case of severe power drop during climb and cruise. An rpm of 13,800 can be used for climb and cruise providing the aircraft does not exceed its placard speeds During this period, the pilot must monitor the jet pipe temperatures as required by the use of the trimmer control. We hope to have a device, to perform this function automatically, installed on our aircraft in the future.

In landing, as throttles are retarded, the propeller will move to the flight fine pitch stop and after the main wheels touch down, the propeller automatically assumes the ground fine pitch setting to give maximum wind-milling drag.

TABLE 1
Cockpit Function Comparison (Approximate)

	Viscount 724	Super Constellation	North Star	DC-7
Levers, Push Rods, Controls, Valves, etc.				
Captain and 1st Officer	23	33	50	76
Flight Engineer		42		
TOTAL	23	75	50	76
Instruments				
Captain and 1st Officer	71	36	96	111
Flight Engineer		98		
TOTAL	71	134	96	111
Switches, Selectors, Pushbuttons, etc.				
Captain and 1st Officer	102	56	131	145
Flight Engineer		100		
TOTAL	102	156	131	145
Warning Lights				
Captain and 1st Officer	46	39	55	55
Flight Engineer		61		
TOTAL	46	100	55	55
GRAND TOTAL ALL FUNCTIONS	242	465	332	387

In the above, where there is a dual instrument, it is considered as two. No circuit breakers and fuses are considered.

MAINTENANCE OPERATIONS

Generally speaking, the introduction of the Viscount aircraft into T.C.A.'s operation was as smooth as, if not smoother than, in the case of the other types of aircraft operated by T.C.A. The Viscount, like any aircraft manufactured by human beings, has presented problems. To date our Maintenance Department have been able to cope with the problems without any serious operational delays.

We have had some difficulty in the cold weather with our heating system and with various seals and materials used throughout the aircraft. You might consider that understandable, in the light of the fact of our severe winters, the manufacturer of this airplane being located in a more temperate zone.

Maintenance personnel have not found too much difficulty in working on this airplane. They have had a normal amount of trouble with British type threads but we were introduced to that problem with the introduction of the Merlin engines with the North Star. Possibly the main new technique required of Maintenance has been in connection with engine adjustments on the Dart. Engine rpm and engine throttle are connected together into a single power lever. When a propeller controller unit, an engine, or a fuel control unit is changed, these various components must be interconnected in such a way that the correct power is obtained at the correct power lever setting.

In setting up a Maintenance check system for this airplane, in its initial stages it was necessary for us to be super cautious. On the other hand, it is general knowledge that an aircraft is somewhat like a woman in that the more contact you have with one, the more it costs you. The check cycle, shown in Table 2, indicates our present checking interval, and the manhours associated with the complete check cycle are comparable to any four engine aircraft. Since the original check cycle was initiated there has been considerable revision to it. For instance, the No. 3 check up to several days ago was done at a 300 hour interval, the No. 4 check at a 1200 hour interval, and so on.

The important thing in any airplane is that the maintenance tie-up of the airplane will not prevent the airplane from flying as many hours as the Traffic Department would like it to fly. At the present time our utilization of the aircraft in scheduled flights is approximately 8 hours per day, whereas the total check and overhaul tie-up is less than 6 hours a day, leaving a considerable amount of leeway for greater utilization of the aircraft.

TABLE 2
Trans-Canada Air Lines 1955
Viscount Maintenance Check System
(Zone Overhaul Man Hour Figures not Included)

Check No.	Max. Check Interval-Flying Hours	Elapsed Time For Check	Approx. Man-Hours Required
1	50	3 Hours	40
2	100	6 Hours	67
3	500	2 Days	775
4	1500	5 Days	2200
5	3000	5 Days	2500

TABLE 3
Trans-Canada Air Lines 1955

Maintenance Delays	Months	Aircraft Type			
		DC-3	724	N/S	1049C
Total Delays	June	33	95	91	39
	July	53	106	118	26
	Aug.	51	115	140	37
	Sept.	36	88	88	32
	Oct.	54	143	93	30
	Nov.				
	Dec.				
Total Revenue Departures	June	5784	969	2650	358
	July	5972	1587	2924	375
	Aug.	5826	1850	2866	378
	Sept.	5425	2051	2614	364
	Oct.	5185	2094	2414	351
	Nov.				
	Dec.				
Delays per 100 Departures	June	.57	9.80	3.4	10.0
	July	.88	6.68	4.0	6.9
	Aug.	.88	6.22	4.8	9.7
	Sept.	.66	4.29	3.3	8.8
	Oct.	1.04	6.83	3.8	8.5
	Nov.				
	Dec.				
Power Plant Delays per 100 Departures	June	.33	1.14	1.5	5.3
	July	.39	1.51	1.4	2.6
	Aug.	.33	1.14	1.9	4.4
	Sept.	.28	.88	1.5	4.4
	Oct.	.40	1.29	1.6	4.5
	Nov.				
	Dec.				
Airframe Delays per 100 Departures	June	.24	8.67	1.9	5.6
	July	.52	5.17	2.6	4.3
	Aug.	.24	5.35	2.9	5.3
	Sept.	.41	3.41	1.8	4.4
	Oct.	.64	5.54	2.2	4.0
	Nov.				
	Dec.				

In addition to the amount of manhours spent on the aircraft check system, aircraft acceptability usually revolves around the number of maintenance delays that the airplane accumulates and, because the power plant is one of the most important systems in the aircraft, the number of featherings and the number of unscheduled engine removals.

A comparative delay picture is given in Table 3 which indicates that, from the overall picture, the Viscount aircraft is doing well for a new aircraft and, from the power plant delay picture, it is probably doing better than anyone might suspect for a relatively new power plant.

From the engine performance point of view itself, Figure 7 shows the engine featherings in the various types of aircraft operated by T.C.A. over a 7 months' period. The Dart again shows up very well comparatively.

Figure 8 shows the unscheduled engine removals in T.C.A.'s operation for various types of aircraft over a 7 months' period. Again, the Dart performance compares well with that of our other engines, especially when you

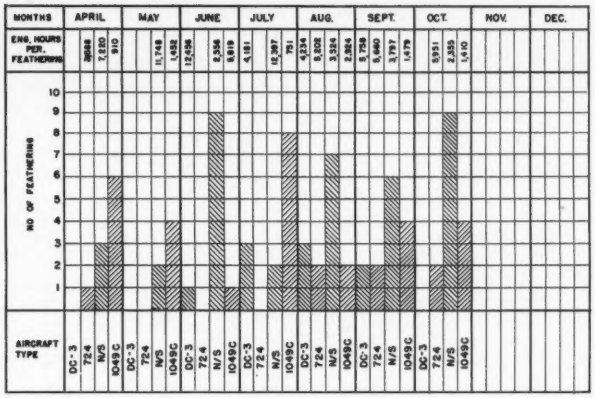


Figure 7
Feathering data

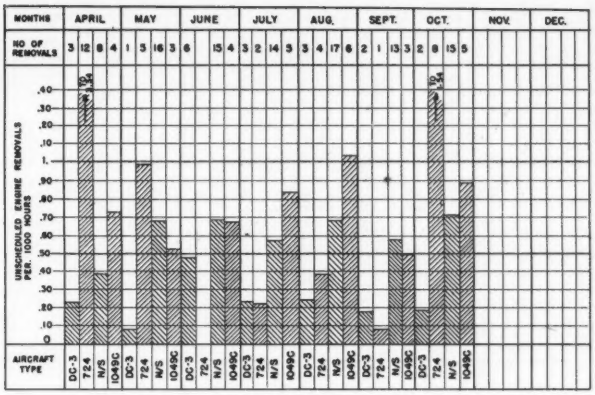


Figure 8
Engine unscheduled removals

consider that we have been operating this engine in scheduled services for only a little over 8 months. You will note a rather drastic rise in the Dart engine removal rate in October. This was due to a situation involving the failure of a cup washer on the primary stage compressor case through bolts. The failed washer fragments in several instances rubbed against the compressor rotor. This is an excellent example of "the tail wagging the dog".

It should be remembered that the statistics given in this paper refer to the initial operating period of the airplane in T.C.A. services. Past experience indicates that it always requires at least a year for the airline to get the 'bugs' out of an airplane which arise as a result of the particular operating procedures and conditions encountered by the airplane.

So much for the mechanical and operational side of our aircraft. The final test of any aircraft, of course, is how much traffic it attracts under competitive conditions. As I pointed out previously, in the selection of the Viscount, it was felt it would have considerable passenger appeal because of its relatively low noise and vibration level. This is borne out, I believe, in the record of the Toronto-New York flight. During the period April 4th to the end of September, 70,171 seats were available and 60,732 revenue passengers carried — a load factor of 86.5%, this being developed in spite of our competitor putting on his latest type of equipment in anticipation of the introduction of a Viscount by T.C.A. This type of performance warms the heart of our Company Management and, as a result, we are pleased on the whole with the Viscount aircraft.

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C.A.I. LOG

SECRETARY'S LETTER

LIST OF MEMBERS

OUR first List of Members has been completed and distributed. It was based on the information furnished by the members themselves, on the cards which we sent out last October; in those cases where no cards had been returned, we gave the members' mailing addresses only, because this was the only information which we knew for certain to be correct. The List is, of course, "as of" December and doubtless much of it is out of date now.

For details for the next List we will probably send out cards again; there is therefore no need to report errors and omissions in this prototype. But we would welcome comments and suggestions for the improvement of the general structure of the List, provided we are not asked for fancy frills and expensive refinements.

INDEX TO VOLUME 1

I do not suppose that many members will go to the trouble of having the 1955 numbers of the Journal bound, but, to those who will, I apologize for the Index to Volume 1 which was distributed last month. It had insufficient "meat" around the edges to allow for trimming. A notice about this appears elsewhere in this issue.

A DAY WITH THE TEST PILOTS

Test Pilots from far and wide, representing most of the Canadian Contractors, the R.C.N. and the R.C.A.F., gathered in Ottawa on the 2nd March to talk about their common problems, and they were good enough to invite me to attend the meeting. It was a most interesting day. The discussion ranged over a variety of technical subjects and a proposal that the test piloting fraternity should set up some sort of association, to provide a forum for the resolution of questions peculiar to their art. It seems an admirable idea and I hope that this association can be set up within the framework of the C.A.I., for it would be to our mutual benefit. Whatever they decide to do, I hope that they will keep very closely in touch with us.

TORONTO

I concluded my tour of the Branches, which started in January in the west and continued in February in Montreal, with a visit to Toronto to attend their March Meeting. They pried me up onto my feet to say a few words – thereby encroaching outrageously on the time which should have been given to their speaker, Mr. J. T. Dyment – and urged me to tell them about my tour of the west and the proposed amendments to the By-laws. Both of these topics had been covered at length in the latest issue of the Journal, but evidently it was too much to expect anyone to have read the thing!

Despite the austere atmosphere of their meetings, held in University lecture halls, they seem to have a lot of fun in Toronto the Good, and their attendance is generally excellent.

MR. C. J. LUBY

As reported under News of Members, Mr. C. J. Luby has gone to England and I feel that I must say just a few words about him. He was President and General Manager of Canadian Steel Improvement Ltd. and, as such, he was a very busy man. Yet, as one of the Councillors for Toronto, he missed only one of the nine meetings of the Council and Executive Committee which have been held since he took office. As the Chairman of the Institute's Finance Committee, he has guided the Institute into a healthy financial position and we were indeed fortunate in having the benefit of his experience in this year of growth and expansion.

Personally I owe him a great deal of gratitude for his advice in our day by day accounting procedures. I probably had more to do with Mr. Luby than with any other member of the Council, except the President; and it was very good to work with him.

BRANCHES

NEWS

Ottawa—Reported by Dr. A. Jaworski

March Meeting

The Chairman of the Branch, Mr. J. L. Orr, opened the meeting of the 14th March with an appeal to the members to mail back at an early date the ballots for the next Executive Committee, and he thanked the Nominating Committee – G/C C. W. Crossland, Chairman, LCDR R. D. G. O'Donnell, Mr. F. R. Thurston and Mr. H. C. Oatway–for preparing the slate and for their willingness to serve as scrutineers. The Chairman informed the members that the April 11th lecture will be preceded by a business meeting when the results of the ballots will be announced with an introduction of the new Officers. Such an early move is due to the Annual Meeting of the Institute, which is scheduled for the 3rd and 4th May in Montreal.

Mr. C. D. Garbutt, from the Montreal Branch, introduced the speaker of the evening, Mr. J. L. Edman of the Bendix Aviation Corporation as an outstanding expert on landing gears, who was in recent years in charge of a special project of the U.S. Air Force investigating landing gear vibration. The subject of the lecture was "Dynamics of Landing Gear Systems" and although the Programme Committee inserted on the announcement a sketch of shapely legs, it was pointed out regretfully by Mr. Garbutt, referring to the sketch, that no samples were brought by the speaker.

Mr. Edman spoke first about the laboratory facilities of Bendix Corporation for landing gear testing. The maximum drop available is of an order of 140,000 lb thus enabling it to cope with landing gear systems for aircraft with gross weights up to 400 tons and ground speed up to 250 miles per hour can be simulated on the test bench. Two films were shown illustrating the laboratory tests and flight tests of a shimmying nose gear; this project took three years to complete. On one of the films, in addition to the vibration of the system with no damping at all, the vibration with an over-damping was illustrated too.

Various methods used by Bendix were briefly described; graphical and analytical approaches and analogue and digital computers. As several of the parameters influencing the landing gear system are of a non-linear character, especially the tires' characteristics, all the methods but the graphical one are very difficult to deal with. Although the arithmetic of the computers is perfect, the equation which is fed in may be wrong and, in this respect, the graphical method serves as a useful cross-check.

On relatively simple problems, such as a vertical load and an un-spinning wheel, the accuracy of the graphical method is quite good because the range of error does not exceed 5%. For the complicated questions, side loads and a spinning wheel, the margin of error is higher–up to 15%.

During the discussion period, a question was asked about the weight penalty incurred in the construction of landing gears in overcoming the fatigue factor. In reply the speaker underlined that the location of maximum stress is very important in this connection and said that a three dimensional photoelasticity laboratory is set up to study this aspect of the subject.

Answering questions about the cause of the Boeing 707 gear failure, Mr. Edman expressed the view that there was no mistake in the design of the gear but the material was at fault and, to some extent, the accident was a blessing in disguise, because the faulty material was eliminated from other parts of the aeroplane as well, Finally, the creeping effect in a landing gear, when engines are tested at full thrust with the brakes on, was briefly discussed.

The Chairman of the Programme Committee, Mr. C. D. Long, thanked the speaker on behalf of the members and the meeting was adjourned at 10.45 p.m. Thirty-nine members and guests were counted from the collected attendance cards.

Toronto—Reported by A. J. Reynolds

Student Section Dinner

The annual dinner of the Aeronautical Club of the University of Toronto was held this year, on the 1st February, in conjunction with the Student Section of the Toronto Branch. A number of senior members, including W/C J. N. Brough, Chairman of the Branch, were present as guests of the Student Section. The speaker on this occasion was Mr. R. J. Templin of the National Research Council, who described the facilities of the Council devoted to aeronautical research.

February Meeting–Student Night

The Branch meeting held on the 14th February was conducted under the chairmanship of Mr. D. M. McGregor, Chairman of the Student Section. Professor T. R. Loudon gave his address "Training the Engineer" which was supplemented by data collected by S/L G. B. Waterman and Mr. R. B. Ferris of Ottawa concerning the present position and future prospects of the Canadian Aeronautical Engineer. As these addresses were described in the February issue of the Journal, on the occasion of their being delivered in Ottawa, they will not be further described here.

Thesis Competition

Four of the talks given by the members of the graduating class in Aeronautical Engineering on their graduating theses were chosen for presentation to a meeting of the Branch, held in Hart House on the 28th February; Mr. E. P. Muntz of the Student Committee was in the Chair. The following talks were presented:

Nuclear Propulsion–Mr. S. Singer

The Pilot, a Factor in the Development of Aircraft–Mr. W. E. B. Roderick

Thin Airfoil Theory–Mr. M. Subotincic

Boundary Layer Control–Mr. D. M. McGregor

Mr. R. E. Klein, Mr. J. W. Ames and Professor B. Etkin acted as the judges and after considerable deliberation–well understood by all present–announced the following awards.

To Mr. Subotincic, a medal for the best talk presented,

To Mr. Roderick and Mr. Singer, certificates representing second and third places, and

To Mr. McGregor, honourable mention.

Each award included a year's membership of the Institute. The prizes were announced by W/C Brough, Chairman of the Branch.

Edmonton—Reported by H. E. Davenport

March Meeting

The March meeting of the Edmonton Branch of the Canadian Aeronautical Institute was held in the Auxiliary Officers Mess on Tuesday, March 13th. Wing Commander J. G. Portlock, Branch Chairman, presided.

After the business meeting, the chairman introduced the guest speaker, Dr. D. B. Scott, University of Alberta physicist who had chosen as his subject, "The Application of Nuclear Power To Aircraft".

Dr. Scott described the structure of the atom and traced the research which led to the first successful experiments in nuclear fission, and went on to explain the problems involved in the application of nuclear power for commercial purposes, and for propulsion of land, sea and air vehicles. The principle of the nuclear reactor was, he said, to convert the heat energy created in the reactor to mechanical energy by means of a turbine, which can be used to drive an electrical generator. In describing the problems associated with industrial reactors, Dr. Scott explained the necessity of thermal and biological shields for protection against heat and harmful radiations. These shields, he explained had to be constructed of iron and concrete of considerable thickness and weight. For this reason he thought that the application of nuclear power to automobiles and trains presented great difficulties. While there was a good supply of fossil fuels such as petroleum and coal, he felt that these vehicles would continue to be propelled by existing fuels. In the case of ships, however, he thought that for large vessels, there was a field for the application of nuclear reactors, which would eliminate the need for carrying large quantities of fuel. The development of nuclear reactors for commercial marine purposes would depend, however, on economic considerations. For naval purposes, there would be strategic advantages in the use of nuclear reactors, which would probably outweigh purely economic considerations.

In the application of nuclear power to aircraft Dr. Scott thought that although there were important strategic advantages, there were also serious difficulties to be overcome before it could be widely used. An important consideration would be to shield the aircraft structure and the occupants from harmful radiation. This would impose a considerable weight penalty which would confine its use to very large aircraft for some time to come. He felt that research in the problems of finding a suitable nuclear power plant for aircraft would, however, continue to be carried on for strategic rather than economic reasons, and that developments could be expected in the foreseeable future.

Dr. Scott felt that the chief field for development of nuclear power in the immediate future was the production of energy for commercial uses. In describing the recent progress in this direction in the United Kingdom, he said that the building of atomic power plants there was undoubtedly spurred on by the desperate need of British industry for another source of energy. This was caused by increasing power requirements and the inability of the coal mines to meet the increased needs of industry.

In Canada, he said, a similar situation is developing in the highly industrialized areas of Ontario and Quebec, where the hydro-electric resources have now been completely developed, and cannot handle greater future needs of industry.

Because of Alberta's wealth in natural gas, oil and coal, he felt that it would be a long time before we would turn to nuclear power, since our resources in these fuels could handle a vastly increased future industrial development.

After his talk there was a general discussion and question period, which concluded a very successful and interesting meeting.

Montreal—Reported by E. C. Norsworthy

March Meeting

A joint meeting with the Montreal Section S.A.E. was held on March 19th, the Speaker being Mr. Karl H. Larsson whose subject was "Turbine Powered Aircraft for the Future". Some 150 members attended.

Mr. Larsson in his talk traced the development and described the differences between the propeller turbine, the so-called by-pass engine or ducted fan and the straight jet engine, and described the design characteristics of each. Mr. Larsson went on to compare the propulsion characteristics and the development status and operational background of each type of engine.

Mr. Larsson summarized the suitability of each type of engine as power-plants for commercial transports of the future, under the headings of Speed, Economy, Payload-Range, Airport Needs, Versatility, and Noise, summarizing the discussion as follows:

(1) The jet engine is superior in speed while the turbojet is basically slower but more economical.

(2) For a given transport mission, the turboprop results in a smaller and lighter aircraft with more versatility and quieter operation.

(3) The by-pass or turbofan represents a cross-breed with characteristics somewhere between the turboprop and turbojet.

(4) Mr. Larsson drew the following conclusions which are quoted directly from his paper:

"I firmly believe that the turbojet transport now in the design and construction stage will take over all first-class passenger traffic on the main routes during the 1960's. A large turboprop transport will be developed for moderate subsonic speed and high load-carrying capacity that will take over tourist and coach passenger traffic, mixed cargo, and later, the growing air freight traffic.

"By that time the turbojet might branch off into a supersonic type, eventually with ramjet augmentation, carrying the blue ribbon first-class passengers and mail.

"The other branch may be a by-pass or ducted fan, subsonic transport, which will take over second-class passenger traffic, leaving third-class, or the so-called B-class to fill the large turboprop, carrying passengers and freight at minimum attainable fares.

"Present piston engine aircraft will be gradually transferred from the world's main routes to secondary lines, and later, after being written off the books, may be re-engined with suitable turboprop engines and live happily for another period of years in areas of the world which do not warrant the modern, larger size planes."

MEMBERSHIP OF THE C.A.I.

as at the Meeting of the Executive Committee of the Council on the 9th March, 1956.

Technical	**1485**
Associates	**60**
Total	**1545**

The Technical grades comprise the following:

Honorary Fellows	10
Fellows	18
Associate Fellows	184
Members	740
Technical Members	421
Technicians	32
Students	80

MEMBERS

ACKNOWLEDGMENT

THE Secretary wishes to acknowledge the many cheques and money orders recently received in payment of annual dues for 1956-57. Membership cards and receipts are being sent out accordingly as expeditiously as possible, but members are asked to accept a few weeks' delay because of the unusually heavy load imposed on the clerical staff at this time of year.

NEWS

J. W. Ames, A.F.C.A.I., who was recently awarded the Canadian Contest Championship Trophy by the Soaring Association of Canada, has been selected to represent Canada in the World Gliding Contests to be held in France from the 29th June to the 13th July next.

G. Glinski, A.F.C.A.I., President of Data Processing Associates Ltd., is conducting a course on electronic analog computation for the staff of the Mechanical Division of the N.R.C. Mr. Glinski has been lecturing on analog and digital data processing at McGill University and Carleton College for the last five years.

C. J. Luby, A.F.C.A.I., has left Canadian Steel Improvement Ltd., of which he was President and General Manager, to take an appointment as Assistant Managing Director of Rotol Ltd., Gloucester, England. Mr. Luby was a member of the 1955-56 Council, representing Toronto, and Chairman of the Finance Committee.

G/C R. McMillan, A.F.C.A.I., has been appointed Chief of Quality Control, R.C.A.F.

J. Fleming, M.C.A.I., has returned from the International Training Centre for Aerial Survey, Delft, and has joined Photo-Air Laurentide, Quebec.

R. T. Gibson, M.C.A.I., of Avro Aircraft Ltd., who has been on temporary duty at Bristol Aircraft (Western) Ltd. for several months, has been transferred back to Toronto. While in Winnipeg he was instrumental in the formation of the Winnipeg Branch and was its first Secretary.

W/C K. J. Regan, M.C.A.I., has retired from the R.C.A.F. after 28 years' service. On retirement he held the position of Chief of Quality Control. He plans to live in Toronto.

A. Stone, M.C.A.I., has left Orenda Engines Ltd. and has taken a position of Senior Aerodynamicist with Solar Aircraft Company, San Diego, Calif.

B. Towler, M.C.A.I., has left Spartan Air Services Ltd. and has been appointed a Designer in the Flight Research Section, N.A.E.

F. A. Woodward, M.C.A.I., has been appointed Manager of the Canadian team visiting France this summer for the World Gliding Contest. The contest which will be held in June and July, will be held at St Yan, near Dijon.

S. Emer, Technical Member, formerly with the Aluminum Company of Canada Ltd., has joined the Lockheed Aircraft Corporation, Marietta, Georgia, as an Aircraft Engineer in the Stress Department.

ADMISSIONS

At a meeting of the Executive Committee of the Council, held on the 9th March, 1956, the following were admitted to the grades of membership shown.

Associate Fellow

B. A. Avery, (on transfer from Member).

C. E. Barkworth, (on transfer from Member).

G/C B. R. Brown, Deputy D.G.M.S. (Air), R.C.A.F.: *289 Clemow Ave., Ottawa, Ont.*

A/V/M M. M. Hendrick, Air Member for Technical Services, R.C.A.F.: *16 Maple Lane, Ottawa, Ont.*

J. R. S. Hutton, Manager (Engineering), Bristol Aero Engines Ltd., 10210 Pie IX Blvd., Montreal North 12, Que.

W/C R. H. Lowry, Staff Officer Medical Services (Air), R.C.A.F., Canadian Joint Staff, 1708 Massachusetts Ave., N.W., Washington, D.C.

R. Lucien, President and Directeur Technique, Messier: *56 Boulevard Maillot, Neuilly sur Seine, France.*

G. E. Woods-Humphrey, President, Renfrew Aircraft & Engineering Co., Ltd., 660 St. Catherine St. West, Montreal, Que.

Dr. T. P. Wright, Vice-President for Research, 333 Day Hall, Cornell University, Ithaca, N.Y.

Member

G. R. Bennett, Section Head, Sales and Service, Canadair Ltd.: *8762 La Salle Blvd., Ville La Salle, Montreal, Que.*

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L. T. Deane, Superintendent Engine Overhaul, Standard Aero Engine Ltd. P.O. Box 764, Winnipeg, Man.

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W/C R. D. H. Ellis, Detachment Commander, R.C.A.F. Station Cold Lake, M.P.O. 503, Grande Centre, Alta.

WO 2 G. A. Feltmate, I/C Maintenance and Repairs, R.C.A.F. Station Cold Lake, M.P.O. 503, Grande Centre, Alta.

W. R. Fryers, Senior Weather Officer, R.C.A.F. Station Cold Lake, M.P.O. 503, Grande Centre, Alta.

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Technical Member

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F. L. Gilbertson, *1636-19th Ave., N.W., Calgary, Alta.*

R. C. Isaac, *Sub P.O. 34, Calgary, Alta.*

W. A. Jones, *1617-19th Ave., N.W., Calgary, Alta.*

W. S. McLaren, *P.O. Box 82, Ancaster, Ont.*

G. S. Moyer, *1330-19th Ave., Calgary, Alta.*

Associate

J. T. Moore, District Traffic and Sales Manager, Trans-Canada Air Lines, 304 Canada Bldg., Winnipeg, Man.

SUSTAINING MEMBERS

NEW SUSTAINING MEMBER

THE following Company has joined the Institute as a Sustaining Member.

Jet Ignition Company

NEWS

The Minneapolis-Honeywell Regulator Co. Ltd. announces the formation of a new design and development group of its Aeronautical Division, which will work in the fields of automatic control and instrumentation. This group will do original work as well as handle the adaptation to Canadian needs of the ideas in aeronautical and ordnance equipment emanating from the parent Company.

The Company has recently bought a 35 acre site in Scarborough Township, Toronto, for the expansion of its facilities, and the first building, of some 70,000 sq ft is intended to accommodate the Aeronautical and Industrial Divisions. The former, though formed less than a year ago, has already outgrown its building in Leaside.

Field Aviation Co. Ltd. are currently engaged in the sectionalizing of Orenda engines for instructional purposes and have developed several new techniques in this class of work. One of these, which has resulted in considerable saving, is the substitution of plastic dummies for many of the real components; the process of the manufacture of these dummies was devised and carried out in the Company's own plastics shop. The sectionalized engines incorporate a colour code denoting changes in temperature and pressure.

Lucas-Rotax Ltd. announces the construction of a new engineering laboratory adjacent the Company's plant at Eglinton Avenue East, Toronto; the new building is expected to be completed in the spring. These new facilities are required to complement the Company's engineering services in the design, development and manufacture of gas turbine engine fuel systems, aircraft electrics and other equipment.

The "Pubs" Committee and the Secretary at work on material for the Journal: (l to r) H. C. Oatway, H. C. Luttman, G/C H. R. Foottit (Chairman) and J. Lukasiewicz. The vacant chair in the foreground was for S/L W. M. McLeish.

ANNUAL GENERAL MEETING

Programme

May 3rd Morning 9.00 a.m.

BUSINESS MEETING

President
MR. R. D. RICHMOND
Chief Development Engineer, Canadair Ltd.

May 3rd Morning 10.45 a.m.

PROPULSION

Chairman
DR. D. L. MORDELL
Chairman, Dept. of Mech. Engr., McGill University

The Development of Rolls-Royce Propeller Turbine Engines
MR. D. P. HUDDIE
Chief Development Engr. (Civil Engines), Rolls-Royce Ltd.

Choice of Design for an Advanced Turbojet
MR. F. H. KEAST
Deputy Chief Engineer, Orenda Engines Ltd.

May 3rd Afternoon 2.00 p.m.

MANUFACTURING

Chairman
MR. R. B. MCINTYRE
Manager, Engine Division, The DeHavilland Aircraft of Canada Ltd.

The Machining and Welding of Titanium
MR. L. B. GRAY
Experimental Shop Manager, Orenda Engines Limited

Transition from Small to Large Aircraft Manufacturing
MR. H. L. MCKEOWN
Director of Operations, Manufacturing Division, Canadair Ltd.

Machining Approach to Aircraft Production
MR. H. F. YOUNG
Chief Production Engineer, Avro Aircraft Limited

May 3rd Evening

DINNER

Chairman
MR. R. D. RICHMOND
President, Canadian Aeronautical Institute; Chief Development Engineer, Canadair Limited

Principal Speaker
AIR VICE MARSHAL M. M. HENDRICK
Air Member for Technical Services

Presentation of the McCurdy Award for 1955 by
THE HONOURABLE J. A. D. MCCURDY

May 4th Morning 9.00 a.m.

DESIGN

Chairman
MR. E. C. GARRARD
Chief Designer, The Fairey Aviation Co. of Canada Limited

Design and Procurement of R.C.A.F. Ground Handling Equipment
F/L B. D. DARLING
Air Materiel Command, R.C.A.F.

Lift and Thrust Creating Systems—Their Application to Short- and Vertical-Takeoff Aircraft
MR. F. C. PHILLIPS
Chief of Aerodynamics and Preliminary Design, Canadair Ltd.
MR. K. IRBITIS
Preliminary Design Engineer, Canadair Ltd.

The Comet 4; Design and Operational Considerations
MR. R. E. BISHOP
Design Director, The DeHavilland Aircraft Co. Ltd.
MR. J. CUNNINGHAM
Chief Test Pilot, The DeHavilland Aircraft Co. Ltd.

May 4th Afternoon 2.00 p.m.

AERODYNAMICS

Chairman
DR. D. C. MACPHAIL
Assistant Director, Div. of Mech. Engr., National Research Council

An Experimental Investigation of the Effect of Surface Roughness on the Drag of a Cone-cylinder Model at a Mach Number of 2.48
DR. J. H. T. WADE
Aerodynamics Engineer, Orenda Engines Limited

Some Performance Problems Associated with a Mach 2 Fighter
MR. J. MORRIS
Assistant Chief Aerodynamicist, Avro Aircraft Limited

Boundary-layer-induced Noise in the Interior of Aircraft
DR. H. S. RIBNER
Research Associate, Institute of Aerophysics, University of Toronto

MAINTENANCE AND OPERATIONS

Chairman
GROUP CAPTAIN E. R. JOHNSTON
Chief Staff Officer, Air Transport Command, R.C.A.F.

The Changing Aspect of Northern Flying
MR. R. N. REDMAYNE
Manager, Air Industries and Transport Association

Airline Engineering Evaluation of Transport Aircraft
MR. A. E. ADES
Assistant Director of Engineering, Trans-Canada Air Lines

Field Data Analysis: Some Techniques Currently Being Developed in the R.C.A.F.
S/L J. E. NEELIN
Logistics Programming Officer, Air Materiel Command, R.C.A.F.
MR. B. LARMOUR
Logistics Analysis Officer, Air Materiel Command, R.C.A.F.

MEETINGS

ANNUAL GENERAL MEETING

Notices giving the full programme of the Annual General Meeting have been sent to all members of the Institute; the programme is also set out on the opposite page.

ABSTRACTS

The following are abstracts of some of the papers to be presented at the Annual General Meeting.

The Development of Rolls-Royce Propeller Turbine Engines

D. P. Huddie–Rolls-Royce

The paper opens with a review of the performance development of Rolls-Royce Propeller Turbine Engines up to and including the Tyne Engine (RB. 109), and shows the improvement in both power output and specific fuel consumption and the means by which the improvements have been achieved.

It then examines the experience gained by the operation of the Dart engine in the Viscount aircraft and makes certain proposals for modification to the methods for testing engines suggested by this experience.

It describes the bench and flight testing which was carried out to define the problems of engine and propeller control with the propeller turbine engine and the current solutions to these problems for the different engine types. This section includes a description of the various safety devices which it has been necessary to include in the control system to prevent prohibitive drag or excessive engine speed following engine or control system failures.

The paper concludes with a review of the work done to assess the relative importance of the various factors affecting propeller noise and the conclusions reached.

Choice of Design for an Advanced Turbojet

F. H. Keast–Orenda

This paper studies some of the requirements of an advanced turbojet engine. Factors considered are design pressure ratio, turbine temperature and size with an attempt to assess the effect of these design variables on engine weight and frontal area. Afterburning engines are also considered. The results of these studies are then applied to various simplified missions of a military character.

The Machining and Welding of Titanium

L. B. Gray–Orenda

The recent developing of techniques in the handling of various grades of titanium has reasonably well assured that material an important place in the aviation industry. Despite the initial, discouraging problems associated with its use, the progress made in solving these difficulties is probably without commercial precedence, due principally to the heavily subsidized research in its manufacture and the vital nature of its physical attraction. In our machining experience, the predicted difficulties were found to be exaggerated. In some cases, the phenomenal stability of the metal offset the reduced cutting speeds required.

The transition period between laboratory methods and development manufacturing techniques to produce semi-production quantities, both in machined parts and welding fabrications has progressed in an amazingly short period of time. Although a very short time ago titanium was considered an extremely difficult metal to machine, parts are now being machined in semi-production quantities at a time rate of only 75% of the time required to machine similar parts in steel. The construction and operation of welding chambers was developed successfully in line with laboratory evaluation of the welds proper. Welding of titanium is now a time-consuming operation due to the necessity of welding inside a chamber. Successful welds have been carried out outside a chamber in laboratory conditions but considerable technical developments are still required before the chamber method can be dispensed with.

Points the paper will cover.

1. Transition from laboratory methods to semi-production.
2. Manufacturing departments placing no restrictions on design in the use of titanium.
3. Manufacturing techniques
   (a) Type of fixturing essential with titanium.
   (b) Grades, angles, cutting rakes generally found most useful.
   (c) Broaching, rake angles and feet per minute.
   (d) Shaping titanium (illustrating Orenda shaper shaping compressor blades).
   (e) Forging titanium blades to accuracies which only a few years ago were impossible to maintain in steel.
4. Fabricating titanium
   (a) Illustration of chamber and typical welding fixture and back-up rings.
   (b) Illustrations of welds outside the chamber.

Transition from Small to Large Aircraft Manufacturing

H. L. McKeown–Canadair

The subject paper will treat with the problems encountered during the changeover from the manufacture of F86 and T33 jets, to the production of the relatively large CL-28 aircraft.

As a base line past and current production programs in the small and medium aircraft field will be briefly reviewed.

Under the following headings the differences between producing small aircraft at relatively high rates and producing a large aircraft at low rates will be presented.

Facilities–Buildings and equipment related to gross product, manpower application related to capital facility and specific problems.

Production–Tooling philosophy, indirect cost relative to direct labour, manpower utilization and specific problems.

Machining Approach to Aircraft Production

H. F. Young–Avro

Present trends in design of supersonic aircraft structures have posed numerous problems for Production Engineers. Not least of these is the requirement of large one piece structural members.

In the past, ribs, spars and fuselage frames were generally fabricated from sheet metal. This necessitated numerous assembly operations. Such machining as was required was of simple character and was confined to turning of bolts, milling of small brackets, spar caps, control fittings, and so on.

The production of large one piece members entails the use of extrusions, forgings, castings and machining from solid material. The use of extrusions and forgings is often limited by economics of tooling and the lack of suitably heavy equipment to produce them.

Production Engineers in the U.K. and the U.S.A. have to a large extent concentrated their efforts on machining structural parts from the solid. The Machine Tool industries have co-operated in design and manufacture of machines capable of high metal removal rates, and with special features to ensure accuracy in the finished parts. Copy machining is becoming one of the most important tools to the Industry. Extensive development work is progressing towards completely automatic control of machine movements, either hydraulically or by use of electronics. However, such well known machines as the Radial Arm Router with suitable adaptations of same may well prove to be an economic solution to the problem of reduction in machining times.

The Design and Procurement of R.C.A.F. Ground Handling Equipment

F/L B. D. Darling–A.M.C., R.C.A.F.

The cost of ground handling equipment (GHE) required to support a modern military aircraft has increased some fifty times since World War II. The complexity and importance of modern GHE is indicated when a comparison is made of this increase to the increase in aircraft costs which has risen some fifteen times.

The design authority for the development of GHE is vested in AFHQ who work in close liaison with the aircraft manufacturer on the design requirement and specification.

Procurement policy for this equipment is determined by the Department of National Defence. Individual purchases are authorized by the Minister of National Defence and are made by the Department of Defence Production on an open tender basis.

These policies together with the design requirement and the cost of the article, which may in turn be affected by import tariff and propriety right costs, are some of the factors which influence RCAF purchase of GHE.

Lift and Thrust Creating Systems–Their Application to Short- and Vertical-Takeoff Aircraft

F. C. Phillips, K. Irbitis–Canadair

The principles employed in the lift- and thrust-producing systems of vertical- and short-takeoff and landing (VTOL and STOL) aircraft are outlined. The practical application of the principles in contemporary and projected VTOL and STOL aircraft designs is discussed. There are presented for these aircraft types, some of their inherent advantages and disadvantages in high- as well as low-speed flight. On this basis some future trends in development of VTOL and STOL aircraft are conjectured.

Family relationships are established between existing, projected and possible additional future configurations of VTOL and STOL aircraft.

The Comet 4: Design and Operational Considerations

R. E. Bishop, J. Cunningham
–DeHavilland

The paper opens by outlining the design development of the Comet and describes the advances in performance and in the structural and aerodynamic aspects, culminating in the Comet 4. The range-payload capabilities of the Comet 4 and its size and capacity are discussed in relation to load factors, service frequency and airfield availability.

The structural evolution of the design is described against the background of fatigue in pressure cabin structures and details are given of the extensive test programme undertaken at Hatfield.

The author then considers some design details of the Comet 4 including engine installation, power controls and emergency systems.

The paper then discusses Comet airline operating experience including a summary of the lessons learned from the world flight of the Comet 3 in December 1955.

An Experimental Investigation of the Effect of Surface Roughness on the Drag of a Cone-Cylinder Model at a Mach Number of 2.48

Dr. J. H. T. Wade–Orenda

Experimental results are presented to show the effect of surface roughness on skin friction. Average skin friction coefficients were obtained, in the absence of appreciable heat transfer for the turbulent flow along the cylindrical portion of a cone-cylinder model at zero angle of attack. The force measurements were made at $M = 2.48$ and $Re = 4.9$ million, using an internal strain-gauge balance. The roughness effects were produced by cutting a V-thread into the surface of the cylinder and covered a range from 6 to 10,000 microinches (peak-to-valley height). It was found that the rough cylinders exhibited no increase in drag above that found on the smooth cylinders until the roughness reached a value of 800 to 1,000 micro inches. This critical height of the surface roughness was found to be about one quarter the height of the laminar sublayer at the start of the cylinder.

Some Performance Problems Associated With a Mach 2 Fighter

J. Morris–Avro

This paper considers the effects of performance requirements on the choice of configuration for a fighter airplane with design speed $M = 2.0$. Particular attention is given to the influence of drag due to lift and trim drag on the choice of wing planform and type of longitudinal control.

The performance characteristics of possible intake configurations are briefly examined.

Boundary-layer-induced Noise in the Interior of Aircraft

Dr. H. S. Ribner
–Institute of Aerophysics

At high speeds the turbulent boundary layer washing portions of the fuselage excites appreciable skin vibration; this sounding-board action gives rise to strong noise in the interior.

For analysis the fluctuating turbulent pressure distribution is represented as a pattern of moving waves (Fourier integral). A calculable ripple in the skin follows underneath each wave; the moving ripple generates Mach waves or, what is the same thing, sound waves. The pattern of sound waves depends on the distribution of wave length and frequency in the initiating turbulent pressure pattern; simple assumptions for this distribution (spectrum) lead to estimates of the noise level.

The Changing Aspect of Northern Flying

R. N. Redmayne–A.I.T.A.

Some of the world's toughest flying conditions are still to be found in Canada's northland. But there have been fundamental changes in the pattern of northern flying in the last few years. The scale has expanded, the equipment altered and the whole concept modified.

Although military requirements have sparked much of this activity, far-reaching effects on our civilian economy can be expected. For aviation could be the key to unlock the riches of the far north.

The potential is there, but we have a lot more to learn if the promise is to be fulfilled.

Field Data Analysis

S/L J. E. Neelin, B. Larmour
–A.M.C., R.C.A.F.

As ground and airborne equipment and systems become increasingly complex, bench testing at the design level prior to field service becomes more difficult, more expensive and less satisfactory as a reliable indicator of field performance. The improvement of methods for obtaining reliable indicators from field data is therefore of increasing importance. This paper presents the authors' findings from current studies in the utilization of field data.

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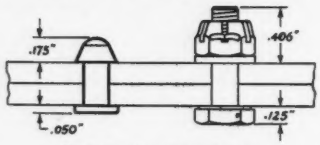

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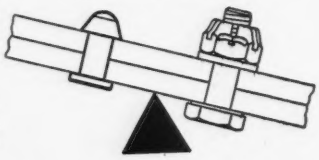

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COVER PAGE AND INDEX TO VOLUME I

It is regretted that the folded sheet, comprising the cover page and index of Volume 1, which was distributed with the March 1956 issue of the Journal, was too small for inclusion in a bound volume of the publication; for this purpose, its dimensions should have been approximately the same as those of an ordinary issue, to allow for trimming during the binding process.

Accordingly the sheet has been reprinted on 8¼" x 11¼". These reprints will not be generally distributed as before, but may be obtained, free of charge, from

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THE qualifications and annual dues set out in the table below are those presently laid down by the By-laws. The rates of dues shown in brackets are those applicable to members who are also members of the R.Ae.S., I.A.S. or E.I.C. and who are also resident in Canada.

In addition to the annual dues, each member is required by the Regulations to subscribe to the Journal of the Institute at a rate not exceeding $3.00 per annum – and now set by the Council at $2.00 per annum.

Applications for membership must be made on the approved forms, which may be procured from the Secretaries of the Branches or from C.A.I. Headquarters. An applicant does not apply for membership in any particular grade, but each application is considered by the Admissions Committee and by the Council, who decide the grade suitable to the applicant's qualifications. On admission, the applicant is informed of his grading and the appropriate entrance fee and annual dues.

The entrance fee is $5.00, except in certain special circumstances.

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Technician	Engaged in technical work in aviation	$3.00 (No Dues*)
Technical Member	Engaged in science, engineering, research, manufacture or operation, in aeronautics or related fields, for 4 years or graduated from an approved school of engineering or science	$5.00 ($2.00*)
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Manuscripts. Manuscripts should be
(a) Typewritten, double-spaced,
(b) On one side of 8½ x 11 white paper,
(c) With wide margins, approximately 1½", and
(d) With pages numbered consecutively.

Manuscripts must be in final form; the addition of material after acceptance by the Institute cannot be permitted.

Titles. The following form should invariably be adopted:–
(a) Titles should be brief;
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(c) The name of the organization with which the author is associated should be shown under his name; and
(d) The author's position in the organization, referred to in (c) above, should be shown as a footnote to the first page.

Summaries. Each paper should be preceded by a summary
(a) Of 100 to 300 words, (10 to 35 lines, double-spaced),
(b) In non-specialist language, so far as possible,
(c) Stating the main conclusions of the paper.

Sub-Headings and Paragraph Numbering. Sub-headings should be inserted by the author at frequent intervals. Paragraphs should not be numbered.

References. References referred to by the author should be treated thus:–
(a) References should be numbered consecutively throughout the paper;
(b) An allusion to a reference should be indicated by a bracketed numeral e.g. "It has been shown by Dr. T. T. James (7) . . . ";
(c) Direct citation of a reference in the text should be written in full, e.g. "As shown in Reference (7) . . . "; and
(d) References should be grouped together in numerical order at the end of the paper, each showing
first, the numerical designation, e.g. "(7)".
second, the author's name, e.g. "James, T. T."
third, the title of his work, e.g. "Aerodynamics and Ballistics"
fourth, the title, volume, issue no, and date identifying the publication in which it appeared, e.g. "R.B.S. Journal, Vol. 7, No. 77, July 1907".

Thus "(7) James, T. T.,–Aerodynamics and Ballistics, R.B.S. Journal, Vol. 7, No. 77, July 1907."

Footnotes. Comments on or amplification of the text should be given in footnotes, appearing at the bottom of the appropriate pages.
(a) Footnotes should be designated alphabetically and consecutively throughout the paper; and
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Figures, Tables and Equations. Reference in the text to
(a) Figures and Tables should be given in full, e.g. "Figure 7", but
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Drawings. Drawings should be
(a) Individually identified by Figure or Table number,
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(a) The caption of a Table should be shown at the top of the Table;
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(d) Accompanied by a manuscript "index" of the Greek letters used in the paper, identifying each letter by a name, e.g. "α–alpha".

In addition the following practices should be adopted:
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$$\frac{A}{B+C}$$

(b) Complicated expressions should be identified by some convenient symbol, if necessary to avoid repetition of the whole expression; and
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Symbols and Abbreviations. Consistency is important;
(a) The symbols recommended in the American Standards Association "Letter Symbols for Aeronautical Sciences" ASA Y10-7–1954 should be used wherever practicable; and
(b) Abbreviations of units should be shown in lower case without periods, e.g. lb, mph, bhp, etc.

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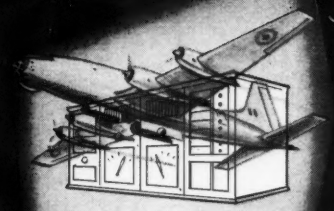
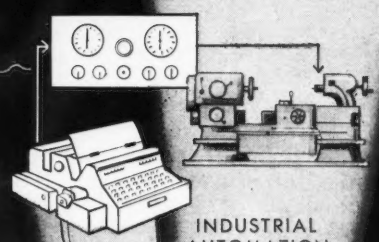
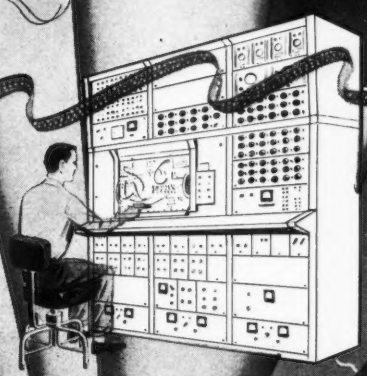


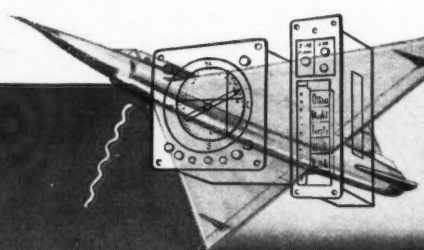
SIMULATION



INDUSTRIAL AUTOMATION



COMPUTERS



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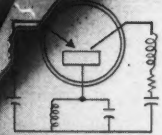

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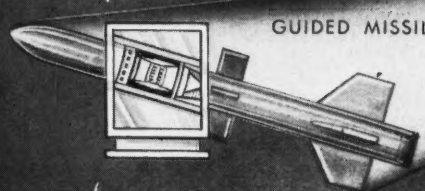

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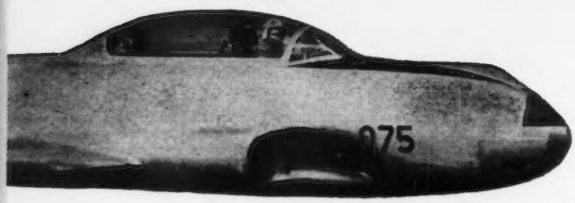

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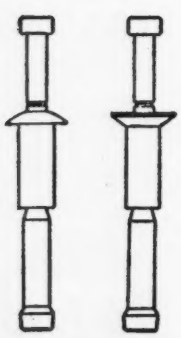

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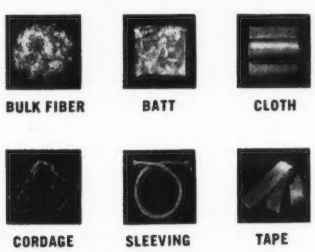

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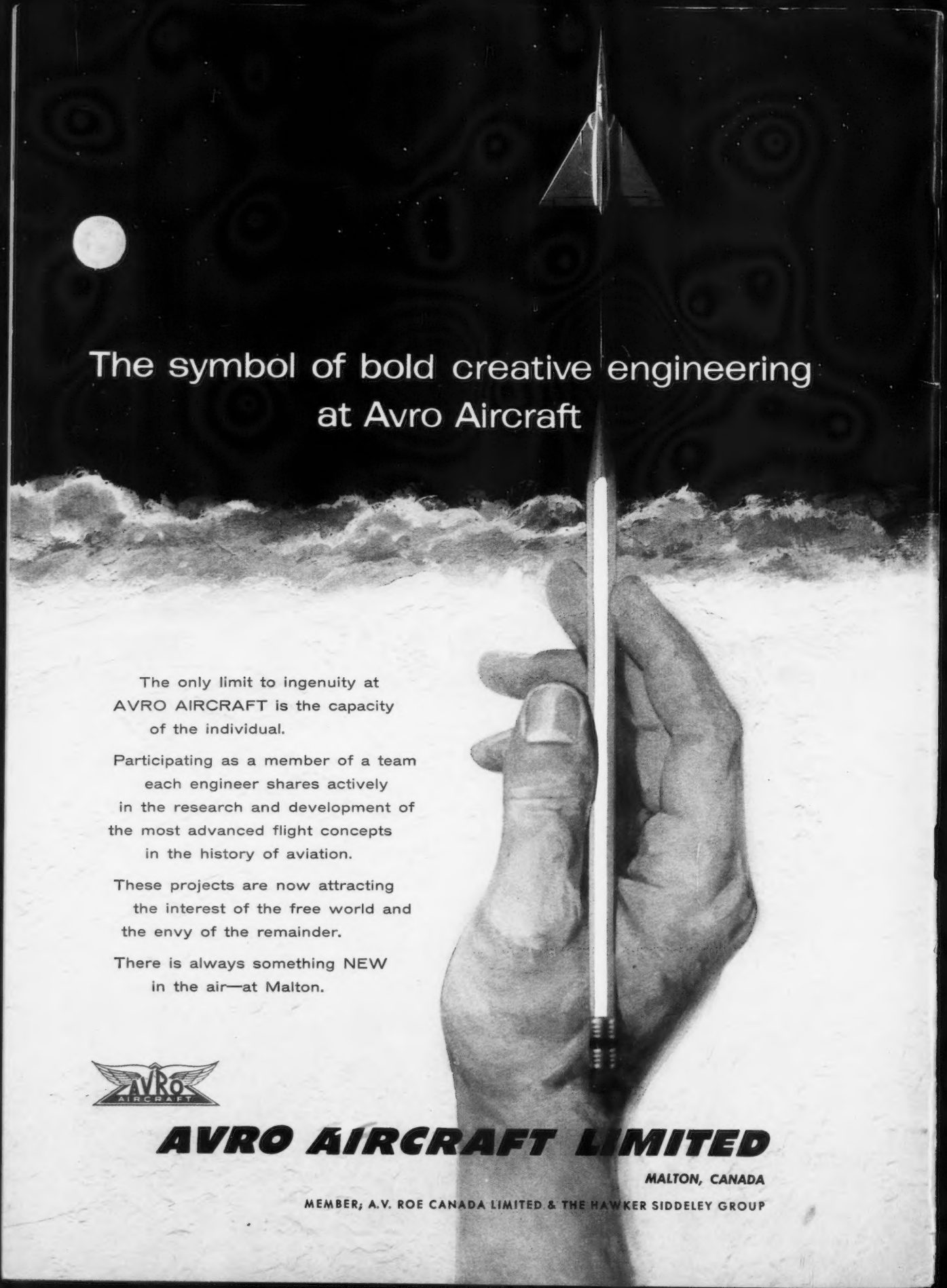
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